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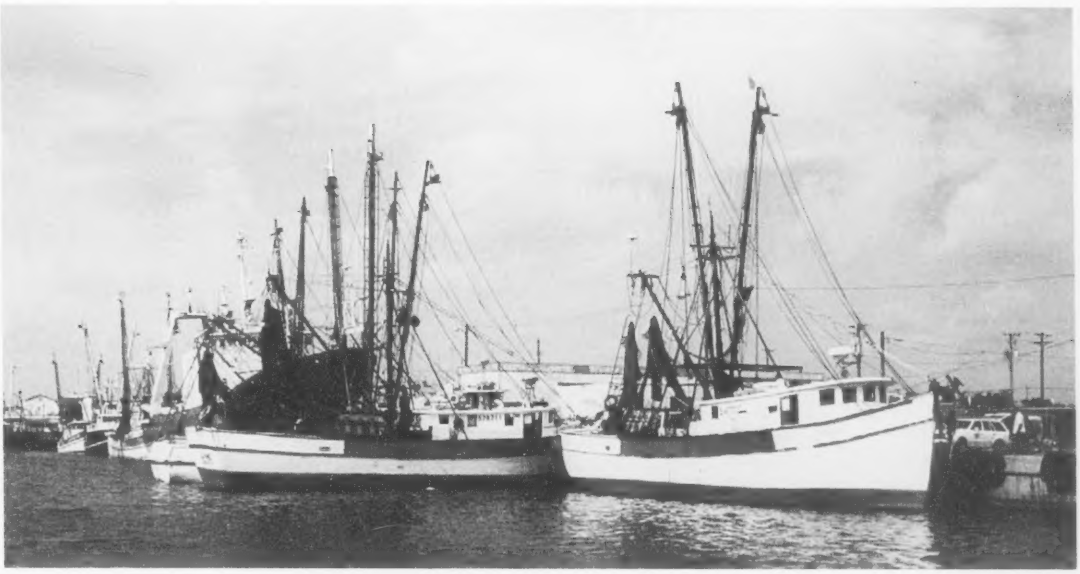

Shrimp Fishery

Marine Fisheries REVIEW

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On the cover: Shrimp boats tied up at Conn Brown Harbor, Texas. Photograph by William B. Folsom, NMFS.

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Descriptions of the U.S. Gulf of Mexico Reef Fish Bottom Longline and Vertical Line Fisheries Based on Observer Data

ELIZABETH SCOTT-DENTON, PAT F. CRYER, JUDITH P. GOCKE, MIKE R. HARRELSON, DONNA L. KINSELLA, JEFF R. PULVER, REBECCA C. SMITH, and JO ANNE WILLIAMS

ABSTRACT—In July 2006, a mandatory observer program was implemented to characterize the commercial reef fish fishery operating in the U.S. Gulf of Mexico. The primary gear types assessed included bottom longline and vertical line (bandit and handline). A total of 73,205 fish (183 taxa) were observed in the longline fishery. Most (66%) were red grouper, Epinephelus morio, *and yellowedge grouper,* E. flavolimbatus. *In the vertical line fishery, 89,015 fish (178 taxa) were observed of which most (60%) were red snapper,* Lutjanus campechanus, *and vermilion snapper,* Rhomboplites aurorubens. *Based on surface observations of discarded under-sized target and unwanted species, the majority of fish were released alive; minimum assumed mortality was 23% for the vertical line and 24% for the bottom longline fishery. Of the individuals released alive in the longline fishery, 42% had visual signs of barotrauma stress (air bladder expansion/and or eyes protruding). In the vertical line fishery, 35% of the fish were released in a stressed state. Red grouper and red snapper size composition by depth and gear type were determined. Catch-per-unit-effort for dominant species in both fisheries, illustrated spatial differences in distribution between the eastern and western Gulf. Hot Spot Analyses for red grouper and red snapper identified areas with significant clustering of high or low CPUE values.*

Introduction

Amendment 22 to the Gulf of Mexico Fishery Management Council's (GMFMC) Reef Fish Fishery Management Plan (GMFMC[1]) dictates mandatory observer coverage. In July 2006, in collaboration with the commercial fishing industry and the GMFMC, the National Marine Fisheries Service's (NMFS) Southeast Fisheries Science Center (SEFSC) implemented a mandatory observer program to characterize the commercial reef fishery operating in the U.S. Gulf of Mexico (Gulf).

This fishery consists of approximately 890 Federally permitted vessels (SERO[2]). Primary gears used include bottom longline, vertical line (bandit or handline), and more recently, modified buoy gear. Although many reef fish species are retained, the predominant target species are groupers, *Epinephelus* spp., and snappers, *Lutjanus* spp.

Longliners off the coast of Florida generally target red grouper, *Epinephelus morio*, in shallow waters, and in deeper waters yellowedge grouper, *E. flavolimbatus*; tilefish (Malacanthidae), and sharks (Carcharhinidae). Vertical line vessel operators target shallow-water grouper (e.g. red grouper), red snapper, *Lutjanus campechanus*, and may also seek yellowedge grouper and vermilion snapper, *Rhomboplites aurorubens*. From historical effort data, most commercial fishing effort for red snapper occurs in the western Gulf of Mexico (SEDAR[3]).

In November 1984, the Reef Fish Fishery Management Plan (GMFMC[4]) was implemented to rebuild declining reef fish stocks. Since that time, Federal regulations have restricted size and landings of several reef fish species. Weight quotas regulate commercial landings for grouper, with 7.57 million lbs for shallow-water grouper and 1.02 million lbs for deepwater grouper (SERO[2]). The current total allowable catch (TAC) for red snapper is 6.3 million lbs, divided between the commercial (51%) and recreational (49%) fishing sectors. An individual fishing quota (IFQ) program for the commercial red snapper fishery was implemented in 2007 and for the grouper and tilefish fisheries in 2010.

Certain areas for reef fish are closed or restricted based on gear type (GMFMC[5]). Federal waters are closed in the Tortugas North and Tortugas South Ecological Reserves in the Florida Keys National Marine Sanctuary and the Madison and Swanson and Steamboat Lumps Marine Reserves off the west central Florida coast. Longline and other buoy gear are prohibited inside

[1]GMFMC. 2005. Amendment 22 to the Reef Fish Management Plan. Gulf Mex. Fish. Manage. Counc., Tampa, Fla. (available at http://www.gulfcouncil.org).

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[2]SERO. 2010. Fishery permits and fishery quotas. Southeast Reg. Off., Natl. Mar. Fish. Serv., NOAA, St. Petersburg, Fla. (available at http://sero.nmfs.noaa.gov).

[3]SEDAR. 2005. Stock assessment report of SEDAR 7 Gulf of Mexico red snapper. Southeast Data Assessment and Review, South Atl. Fish. Manage. Counc., Charleston, SC (available at www.sefsc.noaa.gov/sedar/).

[4]GMFMC. 1984. Reef Fish Management Plan. Gulf Mex. Fish. Manage. Counc., Tampa, Fla. (available at http://www.gulfcouncil.org).

[5]GMFMC. 2010. Commercial fishing regulations for Gulf of Mexico Federal waters. Gulf Mex. Fish. Manage. Counc., Tampa, Fla. (available at http://www.gulfcouncil.org).

the 50-fm contour west and the 20-fm contour east of Cape San Blas, Fla.

In May 2009, an emergency rule to protect sea turtles (Cheloniidae and Dermochelyidae) went into effect prohibiting the use of bottom longline gear east of Cape San Blas, Fla., shoreward of the 50-fm contour. Modification through subsequent regulations (GMFMC[5]) prohibited bottom longline gear east of Cape San Blas, Fla., shoreward of the 35-fm contour from June through August, restricted the number of hooks onboard to 1,000, of which only 750 could be rigged for fishing, and reduced the number of vessels through an endorsement system based on documentation of an average annual landing of at least 40,000 lbs during 1999 through 2007.

The effectiveness of quota systems, size limits, and area closures as management tools has been debated (Coleman et al., 2000; Nieland et al., 2007; Stephen and Harris, 2010). Once a vessel's red snapper quota is reached, for example, the vessel simply targets other reef fish, making red snapper a bycatch species. Currently, the minimum legal size for red snapper is 13 in total length (TL). The minimum size limit for red grouper was reduced from 20 in TL to 18 in TL, effective 18 May 2009 (GMFMC[5]).

The mortality rates of both undersized target species and nontargeted species caught on the various gear types remains a pressing concern. Findings from mark-release mortality studies (Gitschlag and Renaud, 1994; Schirripa and Legault[6]; Burns et al.[7]) indicate variable rates of mortality based on depth and method of capture.

In December 1993, SEFSC's Galveston Laboratory implemented a voluntary observer program to characterize the fish trap, bottom longline, and bandit reel fisheries in the U.S. Gulf of Mexico (Scott-Denton and Harper[8]; Scott-Denton[9]). Observer coverage of the commercial reef fish fishery operating primarily off the west coast of Florida and, to a lesser extent, off Louisiana, was conducted from 1993 through 1995. Data from 576 sets aboard fish trap vessels, 317 sets from bottom longline, and 580 sets from bandit reel vessels were analyzed. Findings from this study revealed a low proportion (<5% of total number caught) of fish discarded dead (immediate mortality) based on surface observations. However, due to the number of fish released in stressed state (air bladder expansion and/or eyes protruding), total predicted red snapper discards of 25% to 30% were used to estimate the number of discarded fish at age that died and thus contributed to fishing mortality (Goodyear[10]).

The continuing goal of the current observer program is to provide quantitative biological, vessel, and gear-selectivity information relative to the directed reef fish fishery. The specific objectives are to: 1) provide general fishery bycatch characterization for finfish species taken by this fishery, 2) estimate managed finfish discard and release mortality levels, and 3) estimate protected species bycatch levels. The specific objectives of this report are to: 1) summarize trip, vessel, environmental, and gear characteristics, 2) quantify fish and protected species composition and disposition based on surface observations, 3) examine size composition of target species, and 4) estimate catch-per-unit-effort (CPUE) trends and spatial distribution for dominant species.

Methods

Protocol sampling modification, randomized vessel selection, and observer deployment through mandatory efforts began in 2006 for the commercial reef fish fishery. NMFS observers were placed on reef fish vessels operating throughout the Gulf of Mexico based on randomized selection stratified by season, gear, and region. Proportional sampling effort, based on coastal logbook data, among seasons and gears in the eastern and western Gulf of Mexico was recommended by SEFSC stock assessment scientists in 2006 and used thereafter for vessel selection stratification purposes using annual updated effort data. Thus, proportional sampling was used to direct coverage levels (based on sea days, the National metric for percent observer coverage levels) toward region and gear strata with higher levels of fishing effort, while continuing to sample strata with lower fishing effort.

In 2008, for the longline fishery, seven trips were not selected through the mandatory process. Instead the trips were based on voluntary cooperation as part of a pilot project to assess the effectiveness of electronic monitoring equipment. Observers placed on these vessels were equipped with closed-circuit video cameras and associated electronics. Results of this study are reported by Pria et al. (2008).

In February 2009, increased coverage was directed toward the bottom longline fishery in the eastern Gulf to monitor for sea turtle interactions. In response to the bottom longline closure inside the 50-fm contour in the eastern Gulf in 2009, some traditional longline vessels used modified buoy gear. This gear type was deployed during three trips inside 50 fm in December 2009 with observers onboard.

Shrimp statistical zones (Patella, 1975) were used to delineate area designations (Fig. 1). Conventionally, statistical areas 1–9 represent areas off the west coast of Florida, 10–12 delineate Alabama/Mississippi, 13–17 depict

[6]Schirripa, M. J., and C. M. Legault. 1999. Status of red snapper in U.S. waters of the Gulf of Mexico: updated through 1998. U.S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., Panama City Lab. Sustainable Fish. Div. Contrib. SFD-99/00-75.

[7]Burns, K. M., N. F. Parnell, and R. R. Wilson, Jr. 2004. Partitioning release mortality in the undersized bycatch: Comparison of depth vs. hooking effects. MARFIN Grant No. NA97FF0349, 36 p., on file at Southeast Reg. Off., Natl. Mar. Fish. Serv., NOAA, St. Petersburg, Fla.

[8]Scott-Denton, E., and D. Harper. 1995. Characterization of the reef fish fishery of the eastern Gulf of Mexico. SEFSC Rep. to Gulf Fish. Manage. Counc. July 17, 1995, Key West, Fla., 45 p.

[9]Scott-Denton, E. 1996. Characterization of the reef fish fishery of the eastern U.S. Gulf of Mexico. MARFIN Grant No. 95MFIH07. Suppl. Rep. to MARFIN Grant No. 94MARFIN17, on file at Southeast Reg. Off., Natl. Mar. Fish. Serv., NOAA, St. Petersburg, Fla.

[10]Goodyear, C. P. 1995. Red snapper in U.S. waters of the Gulf of Mexico. U.S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., Southeast Fish. Sci. Cent., Miami Lab. Rep. Contrib. MIA 95/96-05, 171 p.

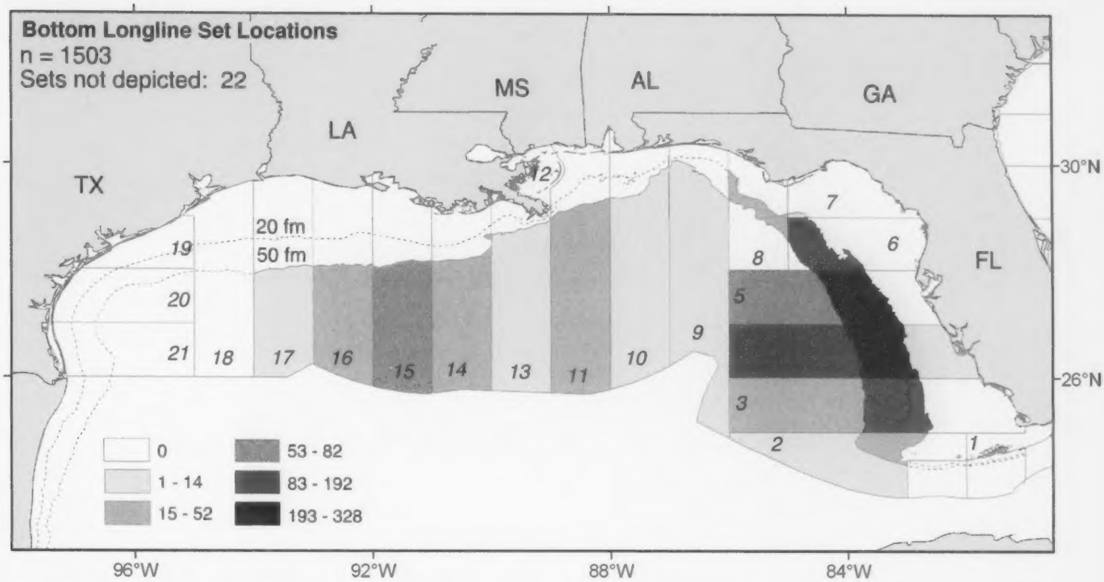

Figure 1.—Distribution of sampling effort (sets) based on observer coverage of the U.S. Gulf of Mexico bottom longline reef fish fishery from August 2006 through November 2009.

Louisiana, and 18–21 denote Texas. For the reef fish fishery, statistical areas 1–8 represent the eastern Gulf and areas 9–21 the western Gulf. Seasonal categories were: January through March, April through June, July through September, and October through December. The three primary gear types assessed included bottom longline, bandit reel, and handline. The latter two were combined to represent the vertical line fishery.

Among the several provisions promulgated under Magnuson-Stevens Conservation and Management Act (MSFCMA) § 303(b)(8) is the mandate for Federal permit holders to have a current Commercial Fishing Vessel Safety Examination decal prior to the selection period for mandatory observer coverage. The safety decal requirement, in combination with other factors, led to low vessel compliance, especially in the first 2 years of the study. A dedicated effort by NOAA Office of Law Enforcement (OLE) has substantially increased compliance (>95%). Additionally, a minimum sea day requirement by gear type was established to prevent early trip termination due to observer effect. Reef fish permit holders are required to carry an observer for a minimum of 7 days during a selection period when using longline gear, 3 days for bandit gear, and 2 days for handline.

Once deployed, vessel length, hull construction material, gross tonnage, engine horsepower, and crew size were obtained for each vessel. For each set (the location of gear placement at a defined time), the type, number, and construction material of the fishing gear were recorded. Latitude, longitude, depth, and environmental parameters including sea state and bottom type were recorded at the start of each set. The total time the gear remained in the water (soak or fishing time) was calculated.

Fishery data were obtained from each set. If a set could not be sampled due to time constraints or weather conditions, a minimum of location, depth, and fishing time were recorded. The condition of fish when brought onboard was categorized into one of the following: 1) live—normal appearance, 2) live—stomach/air bladder protruding, 3) live—eyes protruding, 4) live—combination of 2 and 3, 5) dead on arrival, or 9) not determined.[11] Categories 2 through 4 were combined to represent a stressed condition.

Fate of fish after release was recorded as alive if it swam down or as discarded dead if it swam erratically, floated, or sank, or if undetermined. Nontarget and undersized target species were processed first by recording length, weight, condition when brought onboard, and fate after release to provide an estimate of immediate mortality (number discarded dead divided by the number of total discards).

If venting occurred, air bladders of live discarded fish were punctured in the same manner as demonstrated by the captain and crew if requested. Retained species were processed by recording length, weight, condition when brought onboard, and if kept or retained for bait. Sightings or captures of sea turtles were recorded in accordance with SEFSC protocol (NMFS, 2008). Data pertaining to sea turtle interactions were reported

[11]Category 9 is the default for a condition that is unknown or not recorded.

to SEFSC for annual sea turtle mortality estimates.

On some (19%) vertical line sets, due primarily to time constraints and the magnitude of the catch, not all reels were sampled for the set. The species total number was extrapolated proportionally based on subsampled reels for that set. Negative sets, or sets where no fish were caught, were included in CPUE calculations. No extrapolation procedures were required for longline and modified buoy sets (i.e. all hooks sampled).

Overall catch rates are presented collectively for all years, areas, seasons, and depths. Due to data confidentiality rules, a minimum of three vessels were required for spatial and temporal stratification purposes, and analysis of modified buoy gear data was restricted.

Effort was calculated using methods described by McCarthy and Cass-Calay.[12] The number of hooks set at each location was multiplied by soak time to derive hook-hours. Catch rates were calculated in number of fish per hook-hour. For the vertical line fishery, total soak time was used for one set location using the sum of all hooks per reel. Therefore, effort may be overestimated due to the repeated deployment (e.g. drops) of multiple gear configurations (e.g. hooks) on the same reel at one set location. Moreover, average haul in time was not documented for all sets, therefore not used in the effort calculation. For sets when the average haul in time was recorded, the average value was less than one minute.

Ratio estimation was used for analyses of species-specific catch rates. As described by Snedecor and Cochran (1967) and Watson et al. (1999), the ratio estimation (1) below was used as the sample estimate of the mean.

$$R = \frac{\sum Y}{\sum X} \qquad (1)$$

where: R = ratio estimate,
Y = extrapolated number for species of a particular disposition code for selected strata, and
X = hook-hours for selected strata.

The estimated standard error of the estimate is given in equation 2:

$$s(R) = \frac{1}{\bar{x}}\sqrt{\frac{\sum (Y - RX)^2}{n(n-1)}} \qquad (2)$$

where: $\bar{x}$ = mean of hook-hours for selected strata, and
n = number of sets occurring in selected strata.

A density surface of CPUE, based on number of fish kept per 1,000 hook-hours for dominant species by fishery, was created using Fishery Analyst.[13,14] This is an ArcGIS extension developed to graphically present temporal and spatial trends in fishery statistics (Riolo, 2006). A search radius of 25 km was used to ensure the search parameter encompassed the maximum length of a fishing set. A cell size of 5 km produced the desired resolution.

Density of catch and effort values for each 5 km cell were calculated by summing those values contained within the 25 km search radius and dividing the value by the area of the circle as defined by the search radius. A summary CPUE value for all years combined was calculated for each cell by calculating CPUE values for individual years and dividing by the number of years for which fishing activity occurred in that cell.

To identify patterns in CPUE for the most frequently captured species in each fishery, a local spatial statistic, the Getis-Ord Gi* (Gi*), was calculated using the Hot Spot Analysis tool in ArcGIS[15], to locate clusters of features with similarly high or low values. The Gi* statistic was also calculated for all discarded and kept species in order to assess if geographical areas of particularly high levels of bycatch occurred.

The Hot Spot Analysis tool evaluates each feature within the context of neighboring features. If the value of the feature is high, and the values for all of its neighboring features are also high, it is a part of a hot spot. Conversely, if a feature is surrounded by similarly low values, it is identified as a cold spot. The Gi* statistic is a Z-score test statistic. For statistically significant positive Z-scores, the larger the Z-score is, the more intense the clustering of high values. The Z-score can produce misleading results when used with local statistics because the test assumes independence between features. Since the GIS runs the test to calculate a Z-score for each feature, the test will end up using many of the same neighbors for adjacent features (Mitchell, 2005). For this reason, the statistical tests associated with local measures of spatial autocorrelation for data exploration were used, rather than as confirmatory statistical testing (Nelson and Boots, 2008).

To standardize bycatch (discard) estimates as prescribed in "Evaluating Bycatch" (NMFS, 2004), the coefficient of variation (CV) was used as a measure of precision for bycatch estimates. CV estimates were calculated by dividing the estimated standard error by the estimate of the mean CPUE (number per hook-hour) for Federally managed discarded species. Less than 0.3% of the total fish processed had an undetermined fate code and were assumed to be discarded in an unknown condition.

Length data are given for the dominant target species. Fish measurements were recorded in metric units for age and growth assessment. To be consistent with the current regulatory mandates relative to size limits, metric measurements were converted to U.S. system equivalents. Fork to total length conversions for red grouper were based on metric regression (Lombardi-Carlson

[12]McCarthy, K. J., and S. Cass-Calay. 2006. Standardized catch rates for red grouper from the United States Gulf of Mexico handline, longline, and trap fisheries, 1990–2005. SEDAR 12-DW-16. Southeast Data Assessment and Review, South Atl. Fish. Manage. Counc., Charleston, SC (available at www.sefsc.noaa.gov/sedar/).

[13]Fishery Analyst, Mappamondo GIS, Via Rubens 3, 43100 Parma(PR)–Italy.

[14]Mention of trade names or commercial firms does not imply endorsement by the National Marine Fisheries Service, NOAA.

[15]ArcGIS 9.3 Computer Software. 380 New York Street, Redlands, Calif. 92373.

et al.[16]). Red snapper total lengths were derived from fork length measurements using equation 3 (SEDAR, 2005):

$$TL\,(\text{in}) = 0.1729 + FL\,(\text{in}) * 1.059. \quad (3)$$

After converting, length values were placed into 1 in intervals. Any lengths ranging from 19.000 to 19.999, for example, were categorized as 19 in. Hence, some degree of error is assumed. Only length measurements were considered. Weight data were not recorded for all specimens, therefore were not included in the analysis.

Results

Fishing Characteristics

From July 2006 through December 2009, data from 9,468 sets collected during 308 trips (1,919 sea days) aboard 205 reef fish vessels were analyzed. Number of trips, sets, sea days, and percent coverage levels are given by year and project (Table 1).

Trip, vessel, set, and gear characteristics varied by gear type (Tables 2, 3). Trip length averaged 11.7 days for longline and 4.8 days for vertical line. Vessel length ranged from 23 to 70 ft, with longline vessels typically at the larger end of the range. The majority (≥85%) of vessels were fiberglass construction.

For longline, the distance of mainline set at a location averaged 5.6 nmi. Mean gangion length was 5.8 ft. On average, 991 circle hooks were set at a location. Most hooks (43%) were 13 aught in size and ranged from 12 to 15 aught. In the vertical line sector, the number of reels used at a set averaged 3.3. The majority (51%) of reels were electric. The number of hooks deployed during a set averaged 26 hooks, with circle hooks deployed most often. The majority (43%) of hooks were smaller hooks (8 aught) as compared to longline.

[16]Lombardi-Carlson, L. A., G. R. Fitzhugh, and J. J. Mikulas. 2002. Red grouper (*Epinephelus morio*) age-length structure and description of growth from the eastern Gulf of Mexico: 1992–2001. U.S. Dep. Commer., NOAA. Natl. Mar. Fish. Serv., Southeast Fish. Sci. Cent., Contrib. Ser. 2002-06, 42 p.

Table 1.—Reef fish trips, sets, and sea days by year and project from July 2006 to December 2009.

Trips by Year and Project

Year	Bandit	Handline	Longline	Electronic Monitoring	Buoy Gear	Total
2006	30	8	12			50
2007	72	25	11			108
2008	34	19	5	7		65
2009	28	21	33		3	85
Total	164	73	61	7	3	308

Sets by Year and Project

Year	Bandit	Handline	Longline	Electronic Monitoring	Buoy Gear	Total
2006	1,078	62	201			1,341
2007	2,424	505	194			3,123
2008	1,353	298	110	245		2,006
2009	1,361	310	753		574	2,998
Total	6,216	1,175	1,258	245	574	9,468

Sea Days by Year and Project

Year	Bandit	Handline	Longline	Electronic Monitoring	Buoy Gear	Total	Industry Sea Days	Percent Coverage
2006	184	12	113			309	21,379	1.4
2007	396	69	120			585	38,200	1.5
2008	219	38	45	108		410	37,348	1.1
2009	162	36	397		20	615	36,818	1.6
Total	961	155	675	108	20	1,919	133,745	1.4

Fishing and environmental conditions differed by gear type (Tables 2, 3). Average fishing depth for longline sets was 51.5 fm. Fishing depths were shallower (27.3 fm) for vertical line. Average soak time was 5.1 h for longline and 0.7 h for vertical line. Most sets (≥47%) occurred over rock bottom in seas <2 ft during daylight hours for both gear types.

Bottom Longline Allocation of Sampling Effort

Data from 68 trips aboard 48 bottom longline vessels from August 2006 through November 2009 were analyzed. The capture of 73,205 fish (Table 4) occurred during 1,503 sets deploying traditional longline gear (Fig. 1). For longline, 1,431 sets had associated effort data (7,232 h; 1,395,320 hooks). Approximately 90% of fishing effort, based on hook-hours, occurred in the eastern Gulf. The greatest concentration of effort (hook-hours) occurred in statistical areas 3 through 5 (Fig. 2), with most (35%) in area 4. By season, 20% of the sets occurred from January through March; 52% April through June; 16% July through September; and 12% October through December for all years combined.

Species Composition

Of the 73,205 fish (183 taxa) caught on longline gear, 46% of the individuals were kept, 35% were released alive, 12% were discarded dead, 4% were discarded with an unknown condition, and 3% were retained for bait (Tables 5 and 6). By number, red grouper dominated the catch composition at 56%. Yellowedge grouper comprised 10% of the catch, followed by blueline tilefish, *Caulolatilus microps*, at 5%; red snapper, tilefish, *Lopholatilus chamaeleonticeps*, and Atlantic sharpnose shark, *Rhizoprionodon terraenovae*, each at 3%. All other species combined constituted 20% of the catch.

By category, red grouper, yellowedge grouper, tilefish, and blueline tilefish comprised the majority (82%) of the 33,335 individuals kept by longliners. Four species (red grouper, Atlantic sharpnose shark, smooth dogfish, *Mustelus canis*; and red snapper) accounted for 83% of the released alive category. Of the 25,471 individuals released alive, 42% exhibited visual signs of stress, while 46% exhibited a normal appearance. Of the 2,414 individuals used for bait, the species

caught and used most often for bait were king snake eel, *Ophichthus rex* (29%), and palespotted eel, *Ophichthus puncticeps* (11%). Red grouper, blueline tilefish, Atlantic sharpnose shark, and red snapper comprised the majority (81%) of 9,037 individuals in the discarded dead category. Approximate minimum assumed mortality was: red grouper (20%), blueline tilefish (76%), Atlantic sharpnose shark (34%), and red snapper (27%). The fate of 2,948 individuals was undetermined. Of these, approximately 77% were red grouper.

Table 2.—Trip, vessel, set, gear, and environmental characteristics observed in the longline fishery from August 2006 to November 2009.

Longline				
Trip	Vessel	Set	Gear	Environmental
783 Sea Days 68 trips aboard 48 vessels 1,503 sets	Length: Avg: 48.3 ft Range: 35 to 69 ft (± 8.4 s.d.).	Soak time: Avg: 5.1 h (± 2.9 s.d.) Range: 0.9 to 32.2 h	Mainline material: Cable (92%) Monofilament (7%) Test: Avg: 1,472.8 lbs (± 784 s.d.) Range: 310 to 4,000 lbs	Water Depth: Avg: 51.5 fathoms (± 37.8 s.d.) Eastern: 44.5 Western: 51.5 Range: 19.3 to 212.0
Trip Length: Avg: 11.7 days (± 3.8 s.d.) Range: 4 to 20 days	Hull Construction: Fiberglass: 85% Steel: 10% Fiberglass/wood: 4%	Mainline: Avg length: 5.6 nmi (± 2.0 s.d.) Range: 0.9 to 12.0 nmi	Gangion: Monofilament (99.9%) •Nylon (0.1%) Avg length: 5.8 ft (± 2.1 s.d) Range: 2.5 to 11.0 ft	Sea State: 0 to 2 foot seas: 46% 3 to 5 foot seas: 35% 6 to 8 foot seas: 17% 8+ foot seas: 2%
Crew size: 1 to 3 individuals (excluding captain)	Engine Horsepower: Avg: 277.1 hp (± 205.3 s.d.) Range: 76 to 1400 hp		Hooks: Avg: 991.1 hooks (± 426.4 s.d.) Range: 150 to 2,500 hooks Type: Circle hooks (100%), offset (63.4%), straight (36.6%) Shaft length avg 2.1 in Distance between hooks: Avg: 22.5 ft (± 13.0 s.d.) Range: 7.0 to 75.0 ft Size: 13 aught (43%) Range: 12 to 15 aught Brand: Mustad®: 82% Eagle Claw®: 18%	Bottom type: Rock: 47% Unknown: 14% Shell: 16% Coral: 10% Mud: 8% Sand: 2% Boulder, clay, and grass: 1% each

Table 3.—Trip, vessel, set, gear, and environmental characteristics observed in the vertical line fishery from July 2006 to December 2009.

Vertical Line				
Trip	Vessel	Set	Gear	Environmental
1,116 Sea Days 237 trips aboard 157 vessels 7,391 sets	Length: Avg: 39.2 ft Range: 23 to 70 ft (± 9.6 s.d.)	Soak time: Avg: 0.7 hrs (± 1.1 s.d.) Range: 0.02 to 15.3 h Haul in time: Recorded: 68% Avg: 0.8 min (± 0.6 s.d.) Range: <0.1 to 5.9 min	Reel type: Electric: 51.4% Hydraulic: 21.7% Hand: 27.0% Rod mount: Fixed: 73.1% Portable: 26.7%	Water Depth: Avg: 27.3 fathoms (± 15.8 s.d.) Range: 0.7 to 305.0
Trip Length: Avg: 4.8 days (± 3.6 s.d.) Range: 1 to 17 days	Hull Construction: Fiberglass: 89% Wood: 5% Steel: 4% Fiberglass/wood: 1% Unknown: 1%	Number of reels/set: Avg: 3.3 (± 1.4 s.d.) Range: 1 to 14	Mainline material: Monofilament (76.8%), Cable (13.7%), Mono/nylon/poly (3.2%), Other (6.3%) Test: Avg: 258.3 lbs (± 233.6 s.d.) Range: 12 to 1,400 lbs	Sea State: 0 to 2 foot seas: 59% 3 to 5 foot seas: 31% 6 to 8 foot seas: 8% 8+ foot seas: 2%
Crew size: 0 to 4 individuals (excluding captain)	Engine Horsepower: Avg: 326.9 hp (± 195.6 s.d.) Range: 40 to1200 hp	Hooks: Avg: 26.1 hooks (± 44.8 s.d.) Range: 1 to 330 hooks Type: Circle hooks (83.3%), J-hooks (12.7%), double J-hooks (3.1%), other (0.8%) Size: 8 aught (43%), 9 aught (20%) Range: 1 to 18 aught Brand: Mustad® (44%), Eagle Claw® (0.4%)	Subline material: Monofilament: 97.8% Test: Avg: 127.2 lbs (± 58.5 s.d.) Range: 10 to 800 lbs Hooks/Reel: Avg: 7.4 hooks (± 10.8 s.d.) Range: 1 to 45 hooks	Bottom type: Rock: 67% Unknown: 16% Shell: 2% Coral: 4% Mud: 5% Sand: 5% Wreck: 1% Fishing State: On anchor: 68% Drifting: 24% Trolling: 2% Unknown: 6%

Red Grouper Disposition and Size Composition

All 40,992 red grouper caught using longline were in the eastern Gulf of Mexico, with the exception of two individuals recorded in the western Gulf. Based on visual observations, the majority (43%) of the fish were released alive, 40% were kept, 12% were discarded dead, and 6% were of unknown condition.[17] One red grouper was used for bait.

A total of 36,764 red grouper were measured and ranged from 4 to 37 in TL with the mode of 4,440 individuals at 18 in TL (Fig. 3). Of these, 32% of the fish caught were <18 in TL, the legal minimum size, with 69% released alive, 19% discarded dead, 11% discarded in an unknown condition, and 0.3% kept. Of the 68% of red grouper ≥18 in TL, 62% were kept, 26% were released alive, 8% were discarded dead, and 3% discarded in an unknown condition.

Depths of red grouper captures ranged from 19.3 to 120.5 fm. Most (67%) red grouper were caught between 20–25 fm, followed by 26–30 fm (21%), 31–35 fm (5%), and 36–40 fm (4%). Catch was ≤1% for the remaining zones (Fig. 4).

CPUE and Discard CV

Mean CPUE for all species and dispositions combined was 0.0095 fish per hook-hour (± 0.0002 SE; Table 5). The catch rate estimate for red grouper was 0.0021 fish kept per hook-hour (± 0.0001 SE). Spatial CPUE density (numbers of fish kept per 1,000 hook-hour) for dominant species for all years combined is depicted (Fig. 5–9). Red grouper were caught and retained primarily in statistical areas 2 through 8, with highest density CPUE observed in statistical area 5.

A similar pattern was detected for blueline tilefish with highest density CPUE in the eastern Gulf of Mexico. Yellowedge grouper, tilefish, and scamp, *Mycteroperca phenax*, were distributed throughout the Gulf with high CPUE observed in deeper waters of the western Gulf. Clusters of significantly high

[17]Percentages may not equal 100% due to rounding.

Table 4.—Number of fish observed using longline (*n*=1,503 sets) and vertical line (*n*=7,391 sets) gear in the Gulf of Mexico from July 2006 to December 2009.

Common name	Scientific name	Longline	Vertical line	Total
Red grouper	*Epinephelus morio*	40,992	13,855	54,847
Red snapper	*Lutjanus campechanus*	2,456	27,669	30,125
Vermilion snapper	*Rhomboplites aurorubens*	139	26,045	26,184
Yellowedge grouper	*Epinephelus flavolimbatus*	6,983	104	7,087
Red porgy	*Pagrus pagrus*	568	6,120	6,688
Blueline tilefish	*Caulolatilus microps*	3,591	23	3,614
Gag	*Mycteroperca microlepis*	723	2,624	3,347
Tilefish	*Lopholatilus chamaeleonticeps*	2,199	45	2,244
Atlantic sharpnose shark	*Rhizoprionodon terraenovae*	2,142	83	2,225
Scamp	*Mycteroperca phenax*	993	1,002	1,995
King snake eel	*Ophichthus rex*	1,573	12	1,585
Smooth dogfish	*Mustelus canis*	1,284	35	1,319
Sharks grouped	*General sharks*	1,025	96	1,121
Snowy grouper	*Epinephelus niveatus*	949	168	1,117
Gray snapper	*Lutjanus griseus*	110	822	932
King mackerel	*Scomberomorus cavalla*	16	886	902
Greater amberjack	*Seriola dumerili*	270	613	883
Blacknose shark	*Carcharhinus acronotus*	816	32	848
Gray triggerfish	*Balistes capriscus*	29	808	837
Chub mackerel	*Scomber japonicus*	0	818	818
Yellowtail snapper	*Ocyurus chrysurus*	11	770	781
Pinfish	*Lagodon rhomboides*	1	598	599
Blue runner	*Caranx crysos*	7	525	532
Speckled hind	*Epinephelus drummondhayi*	492	31	523
Lane snapper	*Lutjanus synagris*	93	416	509
Tomtate	*Haemulon aurolineatum*	1	494	495
Almaco jack	*Seriola rivoliana*	39	453	492
Knobbed porgy	*Calamus nodosus*	12	396	408
Spotted hake	*Urophycis regia*	377	3	380
Palespotted eel	*Ophichthus puncticeps*	288	0	288
Jolthead porgy	*Calamus bajonado*	132	154	286
Mutton snapper	*Lutjanus analis*	265	20	285
Sharksucker	*Echeneis naucrates*	213	64	277
Banded rudderfish	*Seriola zonata*	12	255	267
White grunt	*Haemulon plumieri*	4	259	263
Little tunny	*Euthynnus alletteratus*	127	128	255
Lesser amberjack	*Seriola fasciata*	20	219	239
Southern hake	*Urophycis floridana*	230	0	230
Spinycheek scorpionfish	*Neomerinthe hemingwayi*	208	3	211
Great barracuda	*Sphyraena barracuda*	153	45	198
Nurse shark	*Ginglymostoma cirratum*	163	34	197
Sand perch	*Diplectrum formosum*	38	130	168
Gulf hake	*Urophycis cirrata*	168	0	168
Silky shark	*Carcharhinus falciformis*	95	71	166
Lemon shark	*Negaprion brevirostris*	157	8	165
Bearded brotula	*Brotula barbata*	148	13	161
Dolphin	*Coryphaena hippurus*	91	67	158
Blackedge moray	*Gymnothorax nigromarginatus*	141	8	149
Blacktail moray	*Gymnothorax kolpos*	144	3	147
Moray (genus)	*Gymnothorax* sp.	133	8	141
Warsaw grouper	*Epinephelus nigritus*	80	54	134
Jack (genus)	*Seriola* sp.	114	18	132
Blacktip shark	*Carcharhinus limbatus*	87	40	127
Black sea bass	*Centropristis striata*	0	127	127
Remora	*Remora remora*	37	80	117
Florida pompano	*Trachinotus carolinus*	2	114	116
Tiger shark	*Galeocerdo cuvier*	107	6	113
Spotted moray	*Gymnothorax moringa*	83	29	112
Creole-fish	*Paranthias furcifer*	0	107	107
Purplemouth moray	*Gymnothorax vicinus*	97	9	106
Black grouper	*Mycteroperca bonaci*	67	34	101
Cobia	*Rachycentron canadum*	72	28	100
Sand seatrout	*Cynoscion arenarius*	24	74	98
Leopard toadfish	*Opsanus pardus*	79	13	92
Dogfish (genus)	*Squalus*	92	0	92
Bank sea bass	*Centropristis ocyurus*	20	61	81
Bluefish	*Pomatomus saltatrix*	2	78	80
Scalloped hammerhead	*Sphyrna lewini*	76	2	78
Cubera snapper	*Lutjanus cyanopterus*	76	2	78
Dogfish	*Mustelus* sp.	72	5	77
Whitebone porgy	*Calamus leucosteus*	6	67	73
Inshore lizardfish	*Synodus foetens*	66	4	70
Crevalle jack	*Caranx hippos*	9	59	68

continued

Table 4.—(Continued).

Common name	Scientific name	Longline	Vertical line	Total
Queen snapper	*Etelis oculatus*	16	50	66
Red drum	*Sciaenops ocellatus*	22	43	65
Grunt (genus)	Haemulon	0	63	63
Spanish mackerel	*Scomberomorus maculatus*	0	62	62
Sandbar shark	*Carcharhinus plumbeus*	59	2	61
Offshore lizardfish	*Synodus poeyi*	41	18	59
Bar jack	*Caranx ruber*	2	57	59
Blackfin tuna	*Thunnus atlanticus*	49	9	58
Blackbelly rosefish	*Helicolenus dactylopterus*	42	10	52
Cuban dogfish	*Squalus cubensis*	49	1	50
Clearnose skate	*Raja eglanteria*	50	0	50
Wenchman	*Pristipomoides aquilonaris*	23	25	48
Smalltail shark	*Carcharhinus porosus*	48	0	48
Sheepshead	*Archosargus probatocephalus*	0	46	46
Snakefish	*Trachinocephalus myops*	44	0	44
Bull shark	*Carcharhinus leucas*	43	0	43
Silver seatrout	*Cynoscion nothus*	20	18	38
Lizardfish (family)	Synodontidae	31	5	36
Gulper shark	*Centrophorus granulosus*	35	0	35
Sharpnose sevengill shark	*Heptranchias perlo*	33	0	33
Spinner shark	*Carcharhinus brevipinna*	28	2	30
Sand diver	*Synodus intermedius*	27	2	29
Bigeye	*Priacanthus arenatus*	0	29	29
Seatrout (genus)	*Cynoscion* sp.	0	26	26
Littlehead porgy	*Calamus proridens*	1	24	25
Gulf toadfish	*Opsanus beta*	21	4	25
Great hammerhead	*Sphyrna mokarran*	24	0	24
Chain dogfish	*Scyliorhinus retifer*	24	0	24
Short bigeye	*Pristigenys alta*	3	20	23
Ocean triggerfish	*Canthidermis sufflamen*	0	23	23
Squirrelfish	*Holocentrus adscensionis*	3	19	22
Cubbyu	*Pareques umbrosus*	0	22	22
Sand tilefish	*Malacanthus plumieri*	3	17	20
Night shark	*Carcharhinus signatus*	20	0	20
Yellowmouth grouper	*Mycteroperca interstitialis*	9	10	19
Triggerfish (family)	Balistidae	0	19	19
Rock hind	*Epinephelus adscensionis*	1	18	19
Goliath grouper	*Epinephelus itajara*	7	12	19
Wahoo	*Acanthocybium solandri*	10	8	18
Reticulate moray	*Muraena retifera*	18	0	18
Blackbar drum	*Equetus iwamotoi*	0	18	18
Round scad	*Decapterus punctatus*	0	17	17
Hake (genus)	*Urophycis* sp.	16	1	17
Jack (family)	Carangidae	4	12	16
Graysby	*Cephalopholis cruentata*	0	15	15
Tattler	*Serranus phoebe*	0	14	14
Squirrelfishes (family)	Holocentridae	3	11	14
Rainbow runner	*Elagatis bipinnulata*	6	8	14
Black margate	*Anisotremus surinamensis*	14	0	14
Bigeye scad	*Selar crumenophthalmus*	0	14	14
Bluntnose sixgill shark	*Hexanchus griseus*	13	0	13
Red hind	*Epinephelus guttatus*	2	11	13
Grouper (genus)	*Mycteroperca*	13	2	15
Scorpionfish	*Scorpaena* sp.	9	3	12
Rock sea bass	*Centropristis philadelphica*	8	4	12
Horse-eye jack	*Caranx latus*	0	12	12
Toadfish (genus)	*Opsanus* sp.	11	0	11
Silk snapper	*Lutjanus vivanus*	7	4	11
Longtail bass	*Hemanthias leptus*	1	10	11
Dusky shark	*Carcharhinus obscurus*	11	0	11
Bigeye sixgill shark	*Hexanchus nakamurai*	11	0	11
Atlantic croaker	*Micropogonias undulatus*	0	11	11
Smooth puffer	*Lagocephalus laevigatus*	10	0	10
Largescale lizardfish	*Saurida brasiliensis*	9	0	9
Atlantic spadefish	*Chaetodipterus faber*	0	9	9
Hardhead catfish	*Arius felis*	0	8	8
Grunt (family)	Haemulidae	8	0	8
Goldface tilefish	*Caulolatilus chrysops*	1	7	8
Southern stingray	*Dasyatis americana*	6	1	7
Cusk-eel (family)	Ophidiidae	5	2	7
Barracuda (genus)	*Sphyraena* sp.	6	1	7
Atlantic cutlassfish	*Trichiurus lepturus*	2	5	7
Spiny dogfish	*Squalus acanthias*	6	0	6

continued

CPUE for red grouper were located in statistical areas 3 through 8 (Fig. 10). For all kept species, clusters of significantly high CPUE were detected in statistical areas 5, 14, 15, and 16 (Fig. 11). Highest discard CPUE was evident in statistical areas 3 through 6 (Fig. 12).

CV estimates (Table 7) for discarded red grouper, red snapper, greater amberjack, *Seroila dumerili*; and gag, *Mycteroperca microlepis*, were low (≤0.1). Several other species of grouper; jacks, king mackerel, *Scomberomorus cavalla*; and cobia, *Rachycentron canadum*, had values ≤0.5.

Vertical Line Allocation of Sampling Effort

Data from 237 trips were collected aboard 157 vertical line vessels from July 2006 through December 2009, with a total of 89,015 fish processed (Tables 3 and 4). Locations for 7,384 vertical line sets are depicted (Fig. 13). Effort data (5,266 h; 190,202 hooks) were available for 7,285 sets. Approximately 37% of the sampled reels had no catch reported during a set. The majority (75%) of sets were in the eastern Gulf of Mexico. However, the highest concentrated effort (74%), based on hook-hours, occurred in the western Gulf of Mexico (Fig. 14). By season, 23% of the effort occurred from January through March; 21% April through June; 33% July through September; and 22% October through December for all years combined.

Species Composition

Of the 89,015 fish (178 taxa) sampled, 71% of the individuals were kept, 19% were released alive, 6% were discarded dead, 1% were discarded in an unknown condition, and 4% were retained for bait (Tables 5 and 8). By number, red snapper ranked highest in catch composition at 31%. Vermilion snapper comprised 29% of the catch, followed by red grouper (16%), red porgy, *Pagrus pagrus* (7%); gag (3%), and the remaining species combined (14%).

Vermilion snapper, red snapper, red grouper, and red porgy comprised 86% of the 63,351 individuals in the kept category. Three species (red snapper, red grouper, and vermilion snapper)

accounted for 80% of the released alive category. Of the 16,872 individuals released alive, 35% exhibited visual signs of stress, while 61% exhibited a normal appearance.

Of the 2,805 individuals used for bait, the species caught and used most often were chub mackerel, *Scomber japonicus* (29%); pinfish, *Lagodon rhomboides* (20%); and tomtate, *Haemulon aurolineatum* (16%). Red snapper, vermilion snapper, and red grouper comprised 87% of 5,185 individuals in the discarded dead category. Minimum assumed mortality for these species was approximately: red snapper (28%), vermilion snapper (41%), and red grouper (11%). The fate of 802 individuals was not determined.

Red Snapper Disposition and Size Composition

A total of 27,669 red snapper were sampled on vertical line gear. Statistical areas of capture ranged from 3 to 21, with no reported takes in statistical area 12. Approximately 77% of the red snapper were captured in the western Gulf of Mexico, with the remaining 23% captured in the eastern Gulf. The majority (65%) of the fish were kept. Based on visual observations, 24% were released alive, 10% were discarded dead, and 1% discarded in an unknown condition.

A total of 25,650 red snapper were measured and ranged from 6 to 41 in TL, with the mode of 4,102 individuals at 15 in TL (Fig. 15). Of these, 92% were ≥13 in TL, the legal minimum size. Approximately 8% were <13 in TL, with 31% of the individuals discarded dead.

Depths of red snapper capture ranged from 3.3 to 305 fm. Most (29%) red snapper were caught in waters less than 20 fm, followed by 20–25 fm (26%), and 31–35 and 26–30 fm (13% each; Fig. 16). The remaining depth zones comprised 19%. No depth values were recorded for 762 red snapper.

CPUE and Discard CV

Mean CPUE for all species and dispositions was 0.9369 fish per hook-hour (± 0.0311 SE; Table 5). Red snapper mean catch rate was 0.2214 fish kept per hook-hour (± 0.0150 SE). Spatial

Table 4.—(Continued).

Common name	Scientific name	Longline	Vertical line	Total
Shortfin mako	*Isurus oxyrinchus*	6	0	6
Margate	*Haemulon album*	5	1	6
Grass porgy	*Calamus arctifrons*	1	5	6
Atlantic bonito	*Sarda sarda*	2	4	6
Swordfish	*Xiphias gladius*	5	0	5
Sailors choice	*Haemulon parra*	0	5	5
Honeycomb moray	*Gymnothorax saxicola*	4	1	5
Hammerhead (genus) shark	*Sphyrna* sp.	3	2	5
Green moray	*Gymnothorax funebris*	4	1	5
Florida smoothhound	*Mustelus norrisi*	5	0	5
Finetooth shark	*Carcharhinus isodon*	5	0	5
Thresher shark	*Alopias vulpinus*	1	4	5
Atlantic stingray	*Dasyatis sabina*	5	0	5
Starfish (family)	Astropectinidae	4	0	4
Spider (genus) crab	*Libinia* sp.	4	0	4
Southern flounder	*Paralichthys lethostigma*	4	0	4
Snake eel (family)	Ophichthidae	4	0	4
Sea bass (family)	Serranidae	1	3	4
Sailfish	*Istiophorus platypterus*	3	1	4
Queen triggerfish	*Balistes vetula*	3	1	4
Puffer (family)	Tetraodontidae	4	0	4
Porgy (genus)	*Calamus*	3	1	4
Pigfish	*Orthopristis chrysoptera*	0	4	4
Black snapper	*Apsilus dentatus*	0	4	4
Anchor tilefish	*Caulolatilus intermedius*	2	2	4
Spottail pinfish	*Diplodus holbrooki*	0	3	3
Spanish flag	*Gonioplectrus hispanus*	0	3	3
Shoal flounder	*Syacium gunteri*	3	0	3
Saucereye porgy	*Calamus calamus*	2	1	3
Octopus (genus)	*Octopus* sp.	0	3	3
Guaguanche	*Sphyraena guachancho*	0	3	3
Conger eel (family)	Congridae	1	2	3
Conger eel	*Conger oceanicus*	2	1	3
Bonnethead	*Sphyrna tiburo*	3	0	3
Black jack	*Caranx lugubris*	0	3	3
Black drum	*Pogonias cromis*	0	3	3
Bermuda chub	*Kyphosus sectatrix*	0	3	3
Yellowfin grouper	*Mycteroperca venenosa*	0	2	2
Yellow conger	*Hildebrandia flava*	2	0	2
Spotfin hogfish	*Bodianus pulchellus*	0	2	2
Southern puffer	*Sphoeroides nephelus*	1	1	2
Smooth butterfly ray	*Gymnura micrura*	2	0	2
Pufferfish (genus)	*Sphoeroides* sp.	2	0	2
Porgie (family)	Sparidae	0	2	2
Oyster toadfish	*Opsanus tau*	2	0	2
Mackerel (family)	Scombridae	0	2	2
Lefteye flounder (family)	Bothidae	2	0	2
Fish (superclass)	Pisces	2	6	8
Dusky flounder	*Syacium papillosum*	2	0	2
Drum (family)	Sciaenidae	0	2	2
Cero	*Scomberomorus regalis*	0	2	2
Broad flounder	*Paralichthys squamilentus*	2	0	2
Atlantic angel shark	*Squatina dumeril*	2	0	2
Yellow jack	*Caranx bartholomaei*	0	1	1
Whitespotted soapfish	*Rypticus maculatus*	0	1	1
Threadtail conger	*Uroconger syringinus*	0	1	1
Stingray (genus)	*Dasyatis* sp.	1	0	1
Stingray (family)	Dasyatidae	1	0	1
Spotted snake eel	*Ophichthus ophis*	1	0	1
Spanish sardine	*Sardinella aurita*	0	1	1
Spanish hogfish	*Bodianus rufus*	0	1	1
Skipjack tuna	*Katsuwonus pelamis*	0	1	1
Skate (genus)	*Raja*	1	0	1
Shrimp eel	*Ophichthus gomesi*	1	0	1
Sand tiger	*Carcharias taurus*	1	0	1
Saddled grenadier	*Caelorinchus caelorhincus*	1	0	1
Roughtongue bass	*Holanthias martinicensis*	0	1	1
Rosette skate	*Raja garmani*	1	0	1
Porkfish	*Anisotremus virginicus*	0	1	1
Offshore hake	*Merluccius albidus*	1	0	1
Octopus (order)	Octopoda	1	0	1
Ocellated frogfish	*Antennarius ocellatus*	0	1	1
Marbled grouper	*Epinephelus inermis*	0	1	1
Mantis (genus) shrimp	*Squilla* sp.	1	0	1

continued

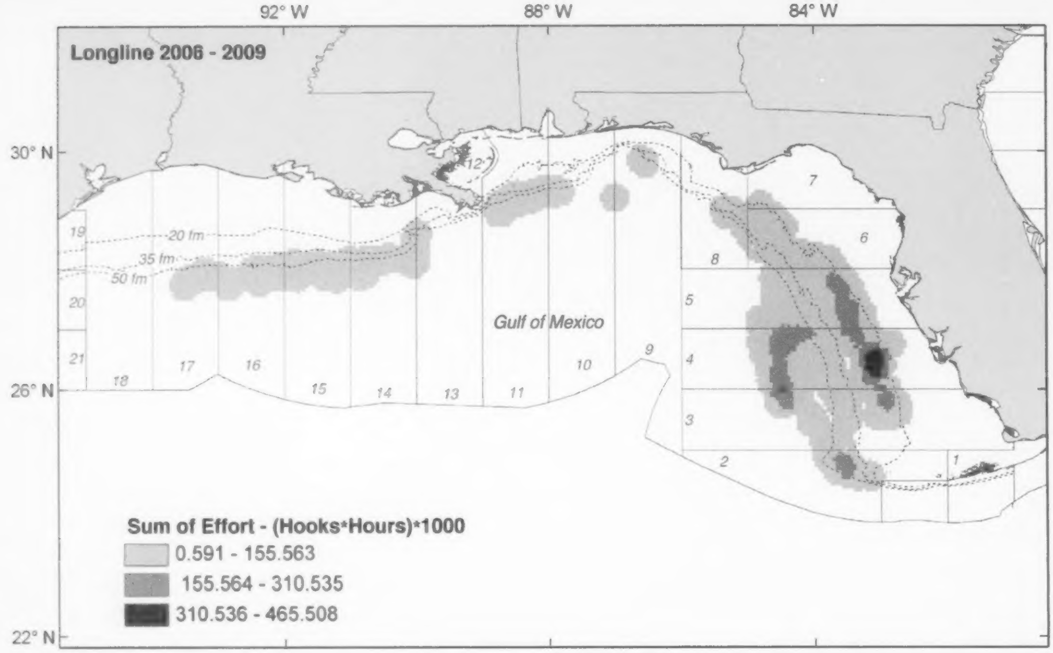

Figure 2.—Distribution of sampling effort (hook-hours) based on observer coverage of the U.S. Gulf of Mexico bottom longline reef fish fishery from August 2006 through November 2009.

CPUE density (numbers of fish kept per 1,000 hook-hours) for dominant species caught using vertical line gear is depicted in Figures 17 through 21. Red snapper were caught and retained throughout the Gulf, with highest density CPUE observed in statistical area 11. Similarly, vermilion snapper occurred in both Gulf regions with a spatial density similar to red snapper. Red grouper were concentrated in the eastern Gulf, with the highest CPUE density observed in statistical areas 3, 4, and 8. High density CPUE for red porgy was found primarily in the eastern Gulf, with the exception of statistical area 16. Gag were caught and retained primarily off Florida, predominantly in statistical areas 5–8.

Cluster locations of statistically significant high CPUE for retained red snapper were most pronounced in statistical areas 8 through 14, 16, and 17 (Fig. 22). For all retained species, clusters of significantly high CPUE were detected primarily in the western Gulf (Fig. 23). Conversely, highest discard CPUE values were observed in the eastern Gulf in statistical areas 5 through 7 (Fig. 24).

Based on number discarded, CV estimates for Federally managed species caught on vertical line gear (Table 9) were low for red grouper, red snapper, vermilion snapper, gag, and greater amberjack ($\leq$0.1). Several other species of grouper, jacks, gray triggerfish, *Balistes capriscus*; king mackerel, and red drum, *Sciaenops ocellatus*, had values less than or equal to 0.5. Higher CV estimates for other species of importance, including

Table 4.—(Continued).

Common name	Scientific name	Longline	Vertical line	Total
Lookdown	*Selene vomer*	0	1	1
Longspine squirrelfish	*Holocentrus rufus*	0	1	1
Jack (genus)	*Caranx*	1	0	1
Gulf hagfish	*Eptatretus springeri*	1	0	1
Gulf flounder	*Paralichthys albigutta*	0	1	1
Gafftopsail catfish	*Bagre marinus*	0	1	1
Dog snapper	*Lutjanus jocu*	0	1	1
Decapod (order)	Decapoda	0	1	1
Big roughy	*Gephyroberyx darwinii*	0	1	1
Cusk-eel (genus)	*Lepophidium*	1	0	1
Cownose ray	*Rhinoptera bonasus*	1	0	1
Cottonwick	*Haemulon melanurum*	1	0	1
Cottonmouth jack	*Uraspis secunda*	0	1	1
Cardinal soldierfish	*Plectrypops retrospinus*	0	1	1
Butterfly ray	*Gymnura* sp.	1	0	1
Bluntnose stingray	*Dasyatis say*	1	0	1
Blackline tilefish	*Caulolatilus cyanops*	0	1	1
Bigeye tuna	*Thunnus obesus*	1	0	1
Barrelfish	*Hyperoglyphe perciformis*	1	0	1
Bank cusk-eel	*Ophidion holbrooki*	0	1	1
Atlantic moonfish	*Selene setapinnis*	0	1	1
Total		73,205	89,015	162,220

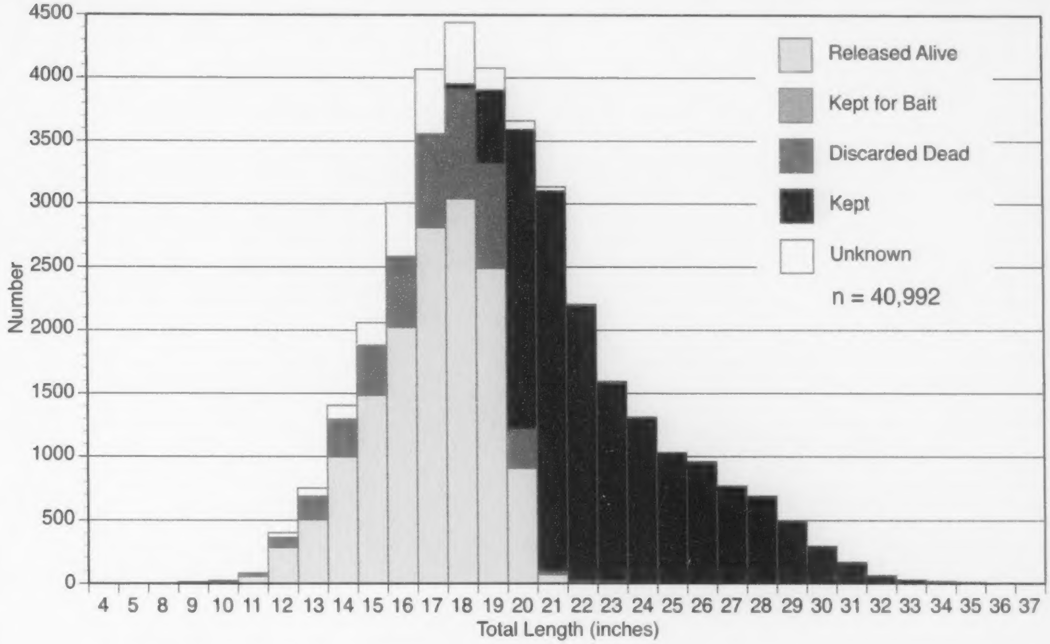

Figure 3.—Size and fate of red grouper caught on bottom longline gear based on observer coverage of the U.S. Gulf of Mexico reef fish fishery from August 2006 through November 2009.

several species of snapper and grouper, were detected.

Interactions with Protected Species in the Reef Fish Fishery

Twenty sea turtles were captured on observed trips utilizing longline gear from 2006 to 2009; three occurred during the electronic monitoring pilot project. One sea turtle was captured on vertical line gear (bandit) during the same time period. Sea turtle mortality and projected take estimates by gear type were reported by SEFSC.[18]

Discussion

To gain a greater understanding of catch rates, bycatch composition,

Table 5.—Species composition and disposition by gear type observed from July 2006 to December 2009.

Longline	Vertical line
73,205 fish of 183 taxa	89,015 fish of 178 taxa
Kept: 46% Red grouper: 49% Yellowedge grouper: 21% Tilefish: 6% Blueline tilefish: 5%	Kept: 71% Vermilion snapper: 37% Red snapper: 28% Red grouper: 12% Red porgy: 9%
Released alive: 35% (42% stressed: air bladder expansion and/or eyes protruding; 46% normal; 12% not recorded) Red grouper: 69% Atlantic sharpnose shark, Smooth dogfish, Red snapper: 5% each	Released alive: 19% (35% stressed: air bladder expansion and/or eyes protruding; 61% normal; 4% not recorded) Red snapper: 39% Red grouper: 34% Vermilion snapper: 7%
Discarded dead: 12% Red grouper: 54% Blueline tilefish: 15% Atlantic sharpnose shark: 8% Red snapper: 5%	Discarded dead: 6% Red snapper: 53% Vermilion snapper: 21% Red grouper: 13%
Unknown: 4% Red grouper: 77% Atlantic sharpnose shark, Gulf hake, Grouped sharks: 3% each	Unknown: 1% Vermilion snapper: 45% Red snapper: 43% Red grouper: 5%
Kept for bait: 3% King snake eel: 29% Palespotted eel: 11% Little tunny: 5%	Kept for bait: 4% Chub mackerel: 29% Pinfish: 20% Tomtate: 16%
Mean CPUE (fish/hook hour): All: 0.0095 (± 0.0002) Kept: 0.0043 (± 0.0001) Red grouper: 0.0021 (± 0.0001)	Mean CPUE (fish/hook hour): All: 0.9369 (± 0.0311) Kept: 0.6500 (± 0.0221) Red snapper: 0.2214 (± 0.0150)
Sea turtle captures: 19	Sea turtle captures: 1

[18]SEFSC. 2009. Estimated takes of sea turtles in the bottom longline portion of the Gulf of Mexico reef fish fishery July 2006 through December 2008 based on observer data. U.S. Dep. Commer., NOAA, NMFS Southeast Fish. Sci. Cent. Contrib. PRD-08/09-07, March 2009, 23 p. [Updated 4/2009, Erratum; updated 6/2009].

Table 6.—Number, condition (when brought onboard), and fate of fish species with $n>25$ caught using longline gear in the Gulf of Mexico from August 2006 to November 2009.

Fate upon release		Kept				Released alive			Kept for bait				Discarded dead				Unknown		
Condition upon capture			Live				Live			Live				Live				Live	
Common name	Total	Total	Normal	Stressed	Dead	Total	Normal	Stressed	Total	Normal	Stressed	Dead	Total	Normal	Stressed	Dead	Total	Normal	Stressed
Red grouper	40,992	16,413	4,186	10,402	259	17,475	5,078	9,543	1			1	4,843	1,010	2,811	760	2,260	98	890
Yellowedge grouper	6,983	6,932	251	5,759	918	5		4	6	1	5		15		4	11	25	4	12
Blueline tilefish	3,591	1,767	551	1,179	37	417	152	264	67	43	14	10	1,331	212	782	332	9	3	5
Red snapper	2,456	784	501	269	3	1,161	376	702	1			1	450	132	208	92	60	16	35
Tilefish	2,199	2,130	996	1,036	93	9	8	1	4		3	1	32	6	10	16	24	3	21
Atlantic sharpnose shark	2,142	20	12	1	7	1,280	1,264	4	50	35	1	14	699	280	2	379	93	79	
King snake eel	1,573	2	2			714	711	1	692	672	4	5	150	110	11	8	15	6	
Smooth dogfish	1,284	1	1			1,176	1,173	2	52	52			44	31		10	11	8	1
Sharks grouped	1,025	1	1			710	701		13	13			275	141		129	26	10	
Scamp	993	955	453	439	14	22	10	5					13	3	6	4	3	1	
Snowy grouper	949	941	114	771	55				2	1	1		6	1	2	2			
Blacknose shark	816	6	6			576	572		15	9		6	162	92		58	57	54	
Gag	723	673	234	417		41	14	22					7	1	4	2	2	1	
Red porgy	568	507	363	119	2	16	13	3	29	24	2	1	10	3	4	3	6	6	
Speckled hind	492	453	99	324	28	17	5	9					22		17	4			
Spotted hake	377	7		3	4	2		2	68	2	60	6	262		163	99	38	5	32
Palespotted eel	288					9	7		271	261		1	6	4		1	2	1	
Greater amberjack	270	124	112	1	7	99	97		14	14			22	13	1	8	11	8	
Mutton snapper	265	264	216	47	1	1	1												
Southern hake	230	7	2	5		5	3	2	50	6	37	6	135	4	116	15	33	2	31
Sharksucker	213	1	1			148	128		47	47			5	4			12	1	
Spinycheek scorpionfish	208	202	62	114	25								5	1	3	1	1		1
Gulf hake	168					13	4	8	2		2		65		56	9	88	4	84
Nurse shark	163					142	127						1				20	11	
Lemon shark	157					153	153						4	1		3			
Great barracuda	153	11	11			15	14		107	79		13	14	7		7	6	5	
Bearded brotula	148	128	81	35	12	1		1	2	1	1		16	1	15		1	1	
Blacktail moray	144					11	11		89	85		4	44	42		2			
Blackedge moray	141	1	1			37	37		81	66		15	16	10		5	6	3	
Vermilion snapper	139	84	18	33	4	32	22	1	11	6		4	11	2	3	4	1		
Moray (genus)	133					9	9		100	78		21	18	5		9	6	1	
Jolthead porgy	132	127	115	3	1				1	1			4			4			
Little tunny	127	1			1				113	14		93	13	2		10			
Jack (genus)	114					71	69	1					5			5	38	38	
Gray snapper	110	105	25	49	1	3											2		
Tiger shark	107					97	94		1	1			4	1		1	5	2	
Purplemouth moray	97					4	4		64	47		17	29	15		12			
Silky shark	95					58	57		2	1		1	34	9		24	1	1	
Lane snapper	93	75	18	49	3	7	3	2	1				5	1	2	2	5		
Dogfish (genus)	92					52	52						38	38			2	2	
Dolphin	91	89	22		67				1				1			1			
Blacktip shark	87	7	4		3	55	54		7	5		2	17	1		15	1	1	
Spotted moray	83					19	19		54	27		23	10	3		7			
Warsaw grouper	80	78	6	71	1								1	1			1		1
Leopard toadfish	79					35	20	14	34	18	16		8	5	3		2	1	1
Cubera snapper	76	76	75	1															
Scalloped hammerhead	76	1	1			56	54		1			1	13			13	5	2	
Dogfish	72					69	68	1					1	1			2	2	
Cobia	72	38	34	1		29	28						2	2			3	3	
Black grouper	67	65	31	15		2		1											
Inshore lizardfish	66					20	3		40	32	1	4	5	1		1	1		
Sandbar shark	59					57	54						2			2			
Clearnose skate	50					9	7		41	39		2							
Cuban dogfish	49					36	36		8	8			5			5			
Blackfin tuna	49	38	17		21	2	2		6			6	2	1		1	1		
Smalltail shark	48					48	48												
Snakefish	44					8	2		33	21	1	11	3	1					
Bull shark	43					42	42						1			1			
Blackbelly rosefish	42	12	11	1		12	9	3					18	2	16				
Offshore lizardfish	41					7	7		26	11	1	13	8	3		3			
Almaco jack	39	19	19			3	3		11	11							6	6	
Sand perch	38					12	5	1	24	18	2	2	1			1	1	1	
Remora	37					34	34		3	2									
Gulper shark	35					30	30						5	5					
Sevengill shark	33					25	25						8			8			
Lizardfish (family)	31					5	5		23	12		11	2			2	1		
Gray triggerfish	29	26	16	8		3	1												
Spinner shark	28	2	2			15	15						9	8		1	2		
Sand diver	27								25	22		3	2			2			
Total (all species)	73,205	33,335	8,778	21,183	1,583	25,471	11,744	10,628	2,414	1,849	178	320	9,037	2,235	4,258	2,149	2,948	407	1,132

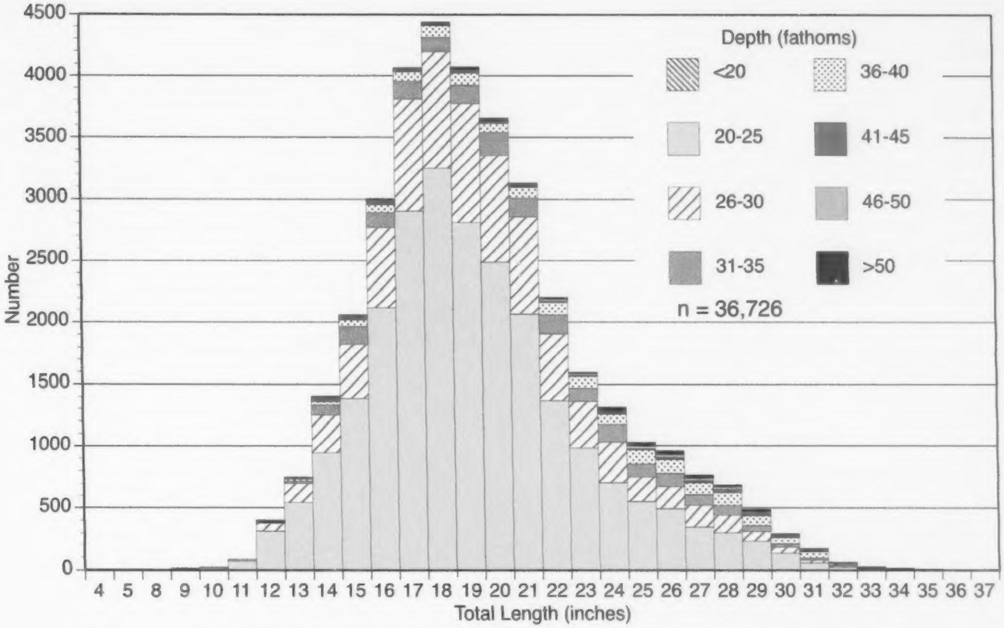

Figure 4.—Number of red grouper by size and depth zone caught on bottom longline gear based on observer coverage of the U.S. Gulf of Mexico reef fish fishery from August 2006 through November 2009.

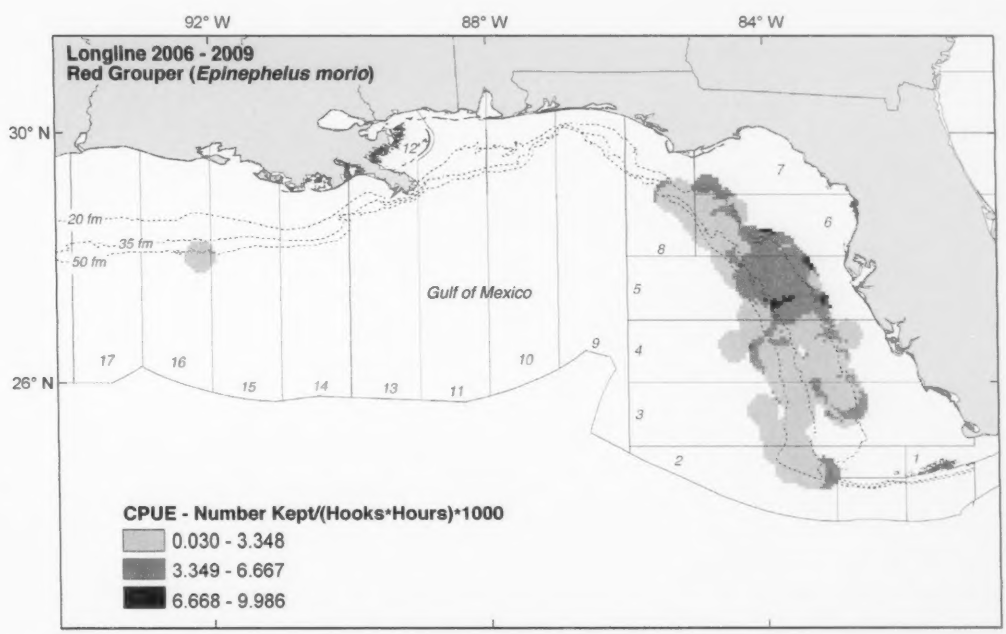

Figure 5.—CPUE density surface for red grouper kept in the bottom longline fishery based on observer coverage of the U.S. Gulf of Mexico reef fish fishery from August 2006 through November 2009.

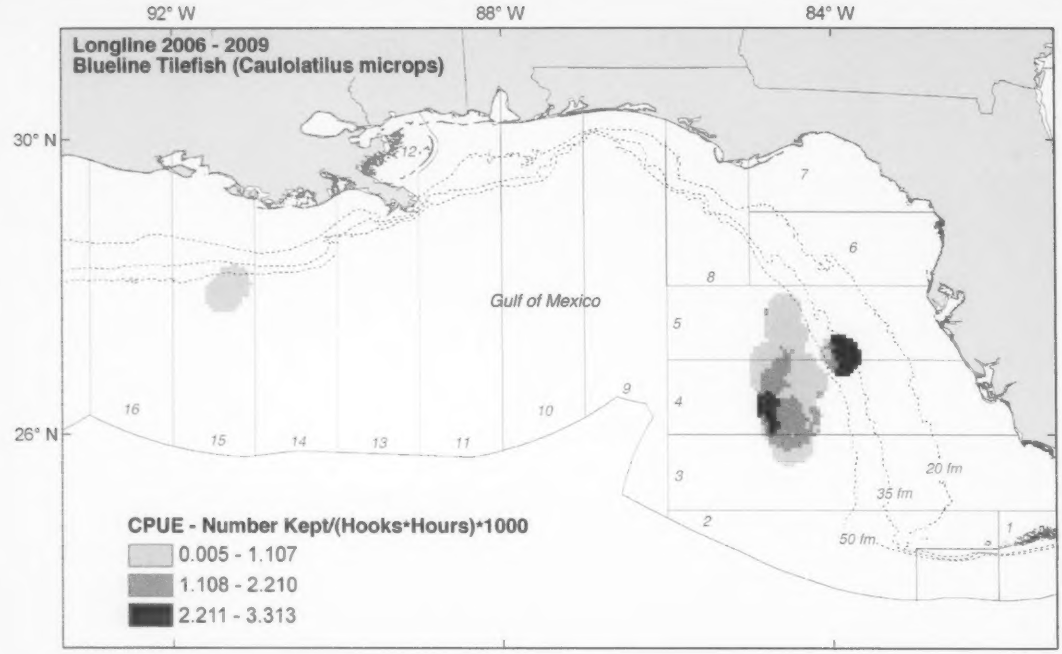

Figure 6.—CPUE density surface for blueline tilefish kept in the bottom longline fishery based on observer coverage of the U.S. Gulf of Mexico reef fish fishery from August 2006 through November 2009.

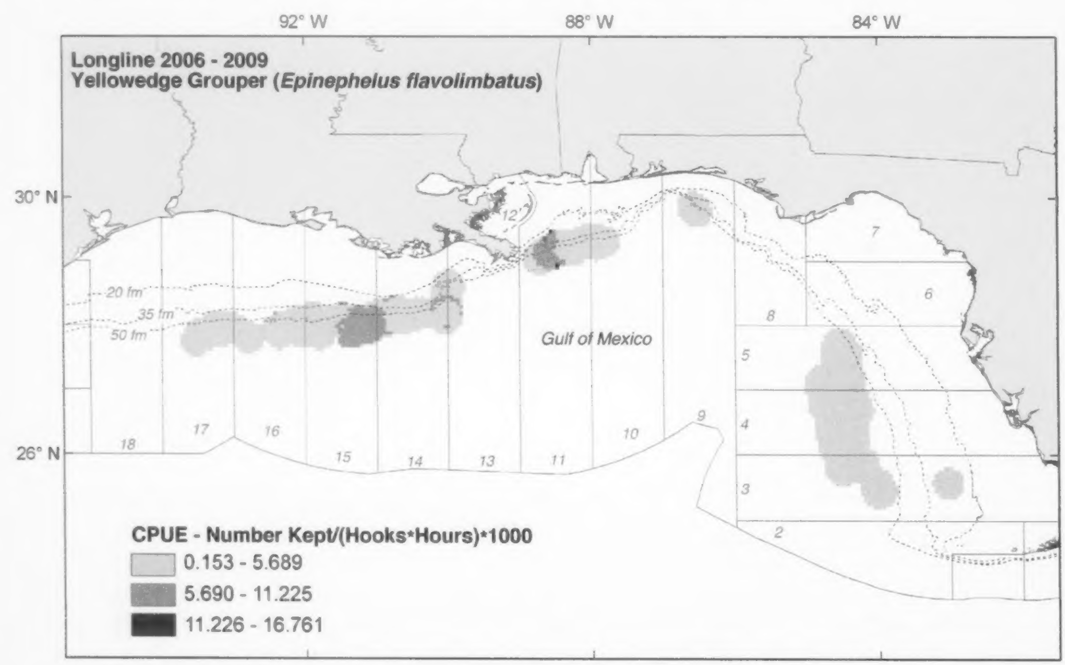

Figure 7.—CPUE density surface for yellowedge grouper kept in the bottom longline fishery based on observer coverage of the U.S. Gulf of Mexico reef fish fishery from August 2006 through November 2009.

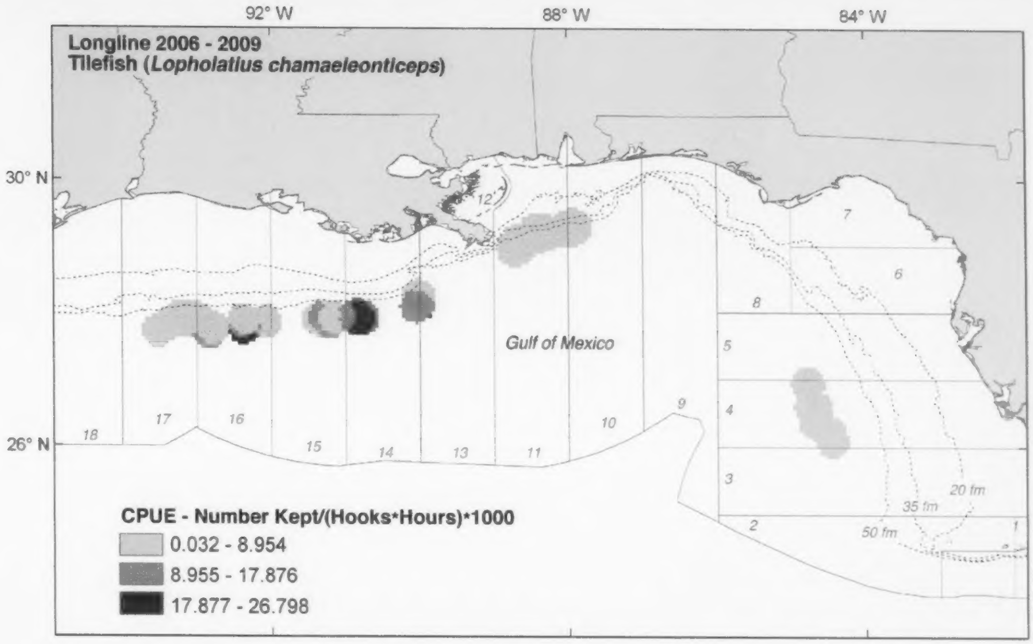

Figure 8.—CPUE density surface for tilefish kept in the bottom longline fishery based on observer coverage of the U.S. Gulf of Mexico reef fish fishery from August 2006 through November 2009.

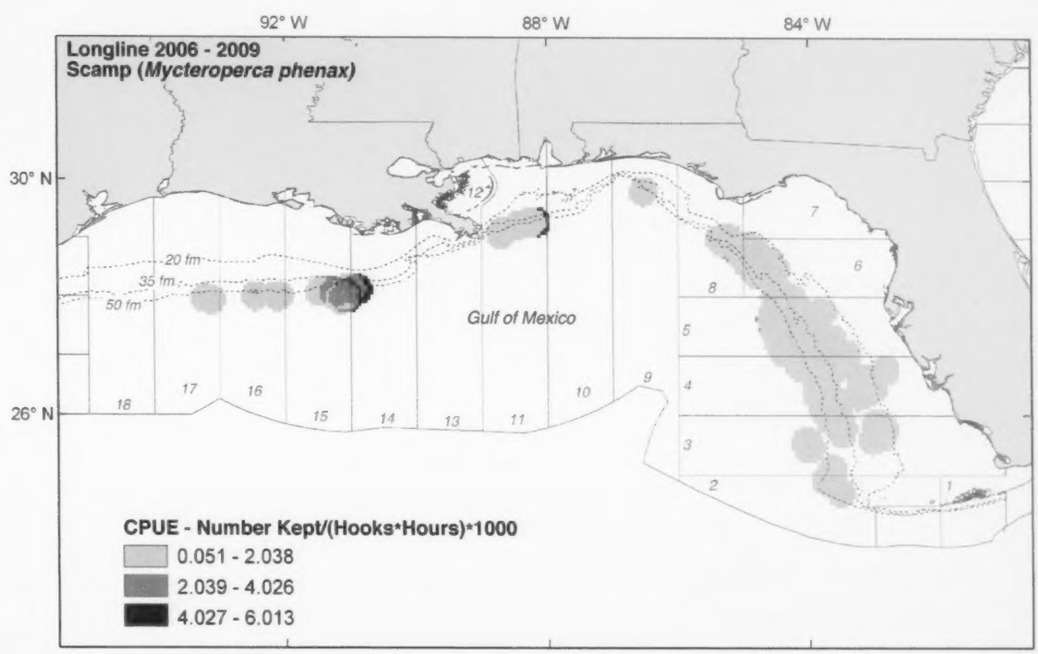

Figure 9.—CPUE density surface for scamp kept in the bottom longline fishery based on observer coverage of the U.S. Gulf of Mexico reef fish fishery from August 2006 through November 2009.

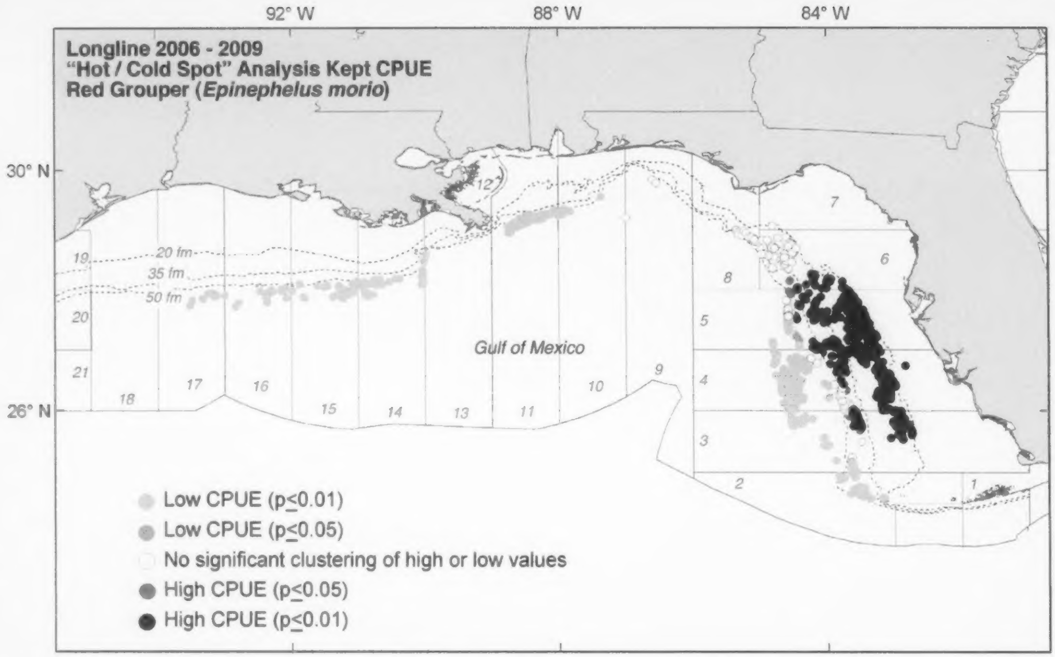

Figure 10.—Hot Spot Analysis for all kept red grouper in the bottom longline fishery based on observer coverage of the U.S. Gulf of Mexico reef fish fishery from August 2006 through November 2009.

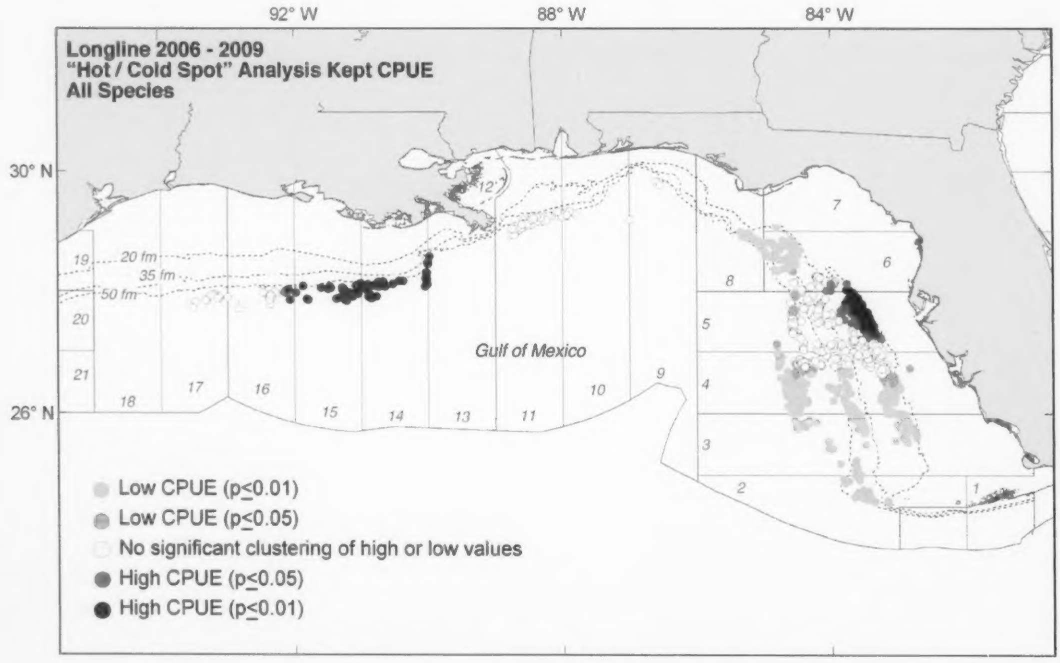

Figure 11.—Hot Spot Analysis for all kept species in the bottom longline fishery based on observer coverage of the U.S. Gulf of Mexico reef fish fishery from August 2006 through November 2009.

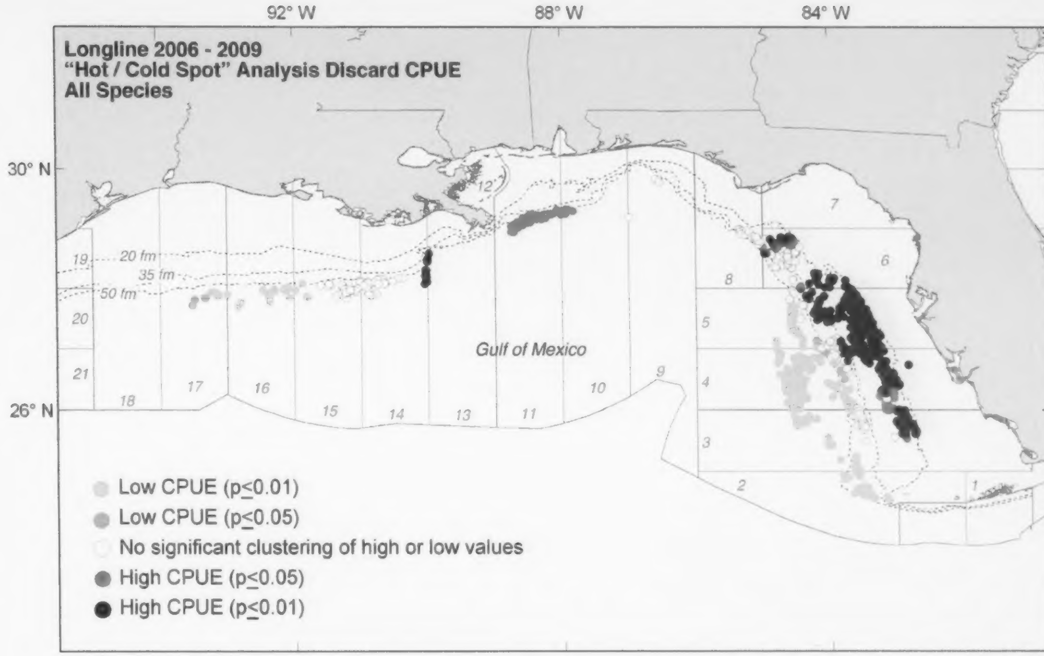

Figure 12.—Hot Spot Analysis for all discarded species in the bottom longline fishery based on observer coverage of the U.S. Gulf of Mexico reef fish fishery from August 2006 through November 2009.

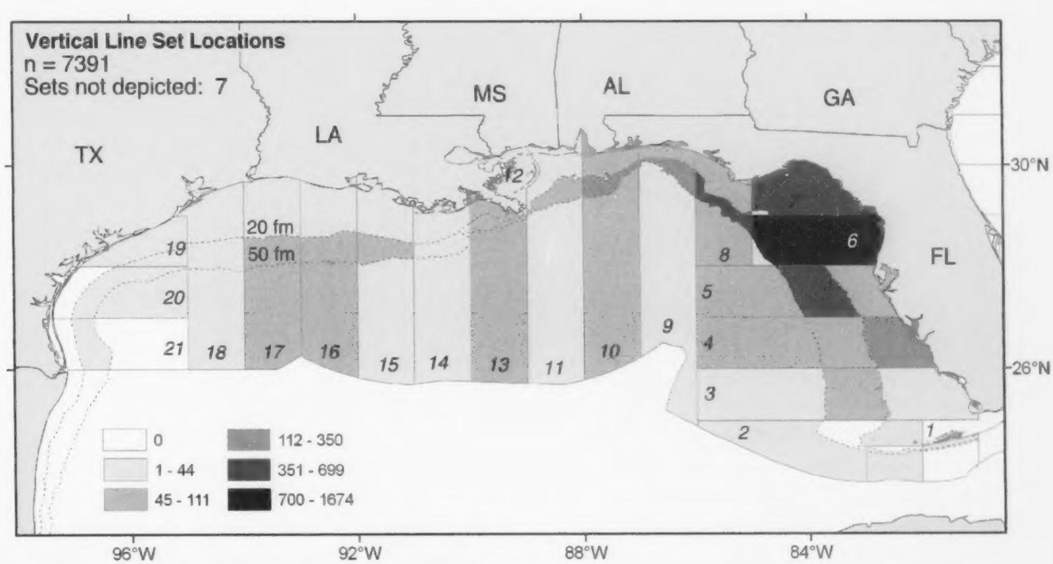

Figure 13.—Distribution of sampling effort (sets) based on observer coverage of the U.S. Gulf of Mexico vertical line reef fish fishery from July 2006 through December 2009.

and discard mortality associated with commercial fishing operations in the U.S. Gulf of Mexico reef fish fishery, a mandatory observer program was established in 2006 based on a proportional randomized sampling design stratified by season, gear, and region. Historically, these data, critical for population assessments, have not been available due to lack of time series and limited geographic ranges for affected species.

Table 7.—Coefficient of variation (CV) for Federally managed discarded species caught aboard longline vessels in the Gulf of Mexico from August 2006 to November 2009.

Common name	Scientific name	n	CV
Red grouper	*Epinephelus morio*	24,081	<0.1
Red snapper	*Lutjanus campechanus*	1,657	0.1
Blueline tilefish	*Caulolatilus microps*	1,824	0.1
Greater amberjack	*Seriola dumerili*	133	0.1
Gag	*Mycteroperca microlepis*	48	0.1
Vermilion snapper	*Rhomboplites aurorubens*	43	0.2
Tilefish	*Lopholatilus chamaeleonticeps*	67	0.2
Cobia	*Rachycentron canadum*	27	0.2
Speckled hind	*Epinephelus drummondhayi*	39	0.2
Yellowedge grouper	*Epinephelus flavolimbatus*	50	0.2
Lesser amberjack	*Seriola fasciata*	19	0.3
Lane snapper	*Lutjanus synagris*	18	0.3
Wenchman	*Pristipomoides aquilonaris*	17	0.3
Snowy grouper	*Epinephelus niveatus*	8	0.4
Scamp	*Mycteroperca phenax*	37	0.4
King mackerel	*Scomberomorus cavalla*	6	0.4
Gray snapper	*Lutjanus griseus*	5	0.5
Banded rudderfish	*Seriola zonata*	10	0.5
Red drum	Sciaenops ocellatus	16	0.6
Red hind	*Epinephelus guttatus*	2	0.7
Warsaw grouper	*Epinephelus nigritus*	2	0.7
Gray triggerfish	Balistes capriscus	2	0.7
Black grouper	*Mycteroperca bonaci*	2	0.7
Yellowtail snapper	*Ocyurus chrysurus*	3	0.7
Mutton snapper	Lutjanus analis	1	1.0
Rock hind	*Epinephelus adscensionis*	1	1.0

Data from this observer program revealed relatively high species richness from the two primary gears (longline n = 183 taxa; and vertical line n = 178 taxa). While diversity was high, red grouper and yellowedge grouper (in longline), and red snapper and vermillion snapper (in vertical line), comprised more than 60% by number of the species caught. These findings are similar to those described by Stephen and Harris (2010) of the snapper-grouper vertical line fishery off South Carolina. Their data revealed high overall diversity; however, a small number of species (17) accounted for 90% of catch.

Hale et al. (2010), through a mandatory bottom longline observer program, examined species composition and disposition of fish captured from longline sets targeting reef fish in the Gulf of Mexico and found, in order of abundance, that red grouper, blueline tilefish, tilefish, and yellowedge grouper comprised 76% of catch. In our current study, these four species accounted for 73% of the catch captured on longline gear. Moreover, disposition of these

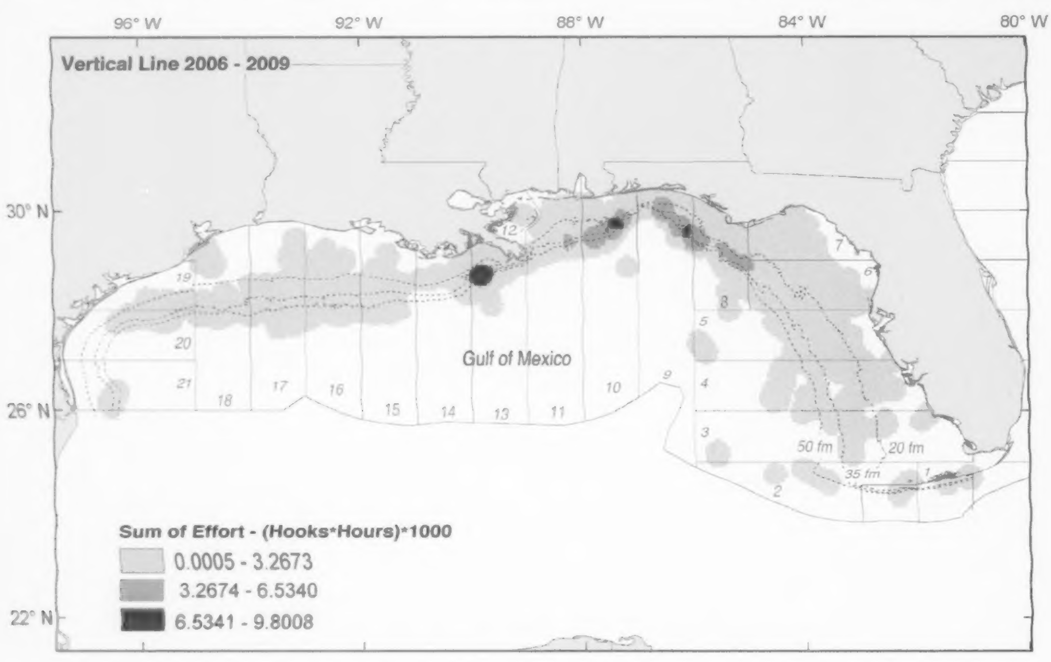

Figure 14.—Distribution of sampling effort (hook-hours) based on observer coverage of the U.S. Gulf of Mexico vertical line reef fish fishery from July 2006 through December 2009.

species was similar between the two programs for red and yellowedge grouper. Blueline tilefish and tilefish discard proportion rates were more variable, and most likely related to the 15 May 2009 tilefish quota closure.

In our current study, 46% of the individuals, predominately red and yellowedge grouper, were kept in longline. In vertical line, a larger percentage (71%) was kept and comprised primarily of vermilion and red snapper. While species-specific minimum size limits differ by region, Rudershausen et al. (2007), Stephen and Harris (2010), and Scott-Denton[9] reported low discard proportions for the vertical line trips; however, low discard

Table 8.—Number, condition (when brought onboard), and fate of fish species with $n > 25$ caught using vertical line gear in the Gulf of Mexico from July 2006 to December 2009.

Fate upon release		Kept				Released alive				Kept for bait				Discarded dead				Unknown			
Condition upon capture			Live				Live				Live				Live				Live		
Common name	Total	Total	Normal	Stressed	Dead	Total	Normal	Stressed	Dead	Total	Normal	Stressed	Dead	Total	Normal	Stressed	Dead	Total	Normal	Stressed	Dead
Red snapper	27,669	17,992	11,368	5,771	38	6,590	4,824	1,673		8	1	6		2,737	1,367	1,308	16	342	104	64	
Vermilion snapper	26,045	23,240	21,994	920	5	1,235	1,095	108		105	64	8	2	1,105	1,037	42	21	360	189	1	
Red grouper	13,855	7,445	1,920	5,143		5,678	1,567	3,722		2	2			692	145	537	5	38	2	25	
Red porgy	6,120	5,971	5,022	196		40	38	1		81	77	1		22	13	8	1	6	1	1	
Gag	2,624	1,565	874	673		1,045	738	296						12	3	8	1	2		1	
Scamp	1,002	898	638	222	1	67	60	7						33	18	15		4		2	
King mackerel	886	868	861		5	11	11			2	1			5	1		4				
Gray snapper	822	775	497	183		44	44							3	3						
Chub mackerel	818					2	2			815	205		1	1							
Gray triggerfish	808	751	523	164		51	41	10						5	4	1		1	1		
Yellowtail snapper	770	722	720	2		37	37			5	5			6	5		1				
Greater amberjack	613	171	148			403	382	1		14	14			23	22			2	2		
Pinfish	598	8	8			13	13			570	103	2		7	6		1				
Blue runner	525	129	129			282	274			78	78			33	30		1	3	2		
Tomtate	494	2	2			16	16			457	279	1		19	19						
Almaco jack	453	285	280			105	103			52	52			11	10		1				
Lane snapper	416	388	141	242		9	3	6		3	2		1	16	12	3	1				
Knobbed porgy	396	377	293	1		6	6			13	13										
White grunt	259	118	108	10		58	58			50	47	3		25	25			8	8		
Banded rudderfish	255	55	54	1		87	87			65	59	1		34	34			14	14		
Lesser amberjack	219	139	121			62	62			9	9			9	9						
Snowy grouper	168	150	18	132		5		5						13	3	10					
Jolthead porgy	154	136	133	3		10	10			4	3	1		3	3			1			
Sand perch	130					6	5	1		123	49	28						1			
Little tunny	128	6	6			20	18			93	86		5	8	7		1	1	1		
Black seabass	127	67	61	6		54	45	9		2	1	1		3	2	1		1		1	
Florida pompano	114	112	112			2	2														
Creole-Fish	107	93	55	37		1	1			9	7	1	1	3	2	1		1		1	
Yellowedge grouper	104	88	1	86										15		15		1		1	
Sharks grouped	96					82	75			2	2			10	10			2			
Atlantic sharpnose shark	83	2	2			73	67			2	2			6	6						
Remora	80	1	1			61	58							18	18						
Bluefish	78	25	25			6	6			32	32			14	14			1	1		
Sand seatrout	74	30	11	17	2	5	4	1		6	5	1		31	18	13		2	2		
Silky shark	71	2	2			68	67							1	1						
Whitebone porgy	67	61	21		1	1	1			1	1			3	2			1	1		
Dolphin	67	45	45			3	3			19	19										
Sharksucker	64	2	1			58	54			1	1			3	3						
Grunt (genus)	63					2	2			60	60			1	1						
Spanish mackerel	62	44	44			13	13			3	3			2			2				
Bank seabass	61					22	10	12		26	10	2		13	4	9					
Crevalle jack	59					56	56			2	2			1	1						
Bar jack	57	44	37			8	7			4	4							1	1		
Warsaw grouper	54	33	3	29		12	2	10						8		8		1		1	
Queen snapper	50	48	31	17		1		1										1			
Sheepshead	46	46	39	7																	
Tilefish	45	44	13	31										1		1					
Great barracuda	45					23	21			4	4			18	17	1					
Red drum	43					37	17	19		1	1			5	1	4					
Blacktip shark	40					32	30							6	6			2	1		
Smooth dogfish	35	2	2			28	16							5	4						
Nurse shark	34					31	28							2	2			1			
Black grouper	34	32	15	11		2	1	1													
Blacknose shark	32					27	27							5	4		1				
Speckled hind	31	17	4	12		8	3	5						6	2	4					
Spotted moray	29					19	19			6	5			4	4						
Bigeye	29	26	26			2	2							1	1						
Cobia	28	13	12		1	14	14							1	1						
Seatrout (genus)	26	7	1	1		8	8			2	2			9	9						
Wenchman	25	4	1	3		2	1	1						19	5	14					
Total (all species)	89,015	63,351	46,602	13,988	55	16,872	10,350	5,914	0	2,805	1,363	61	12	5,185	2,972	2,086	63	802	333	98	0

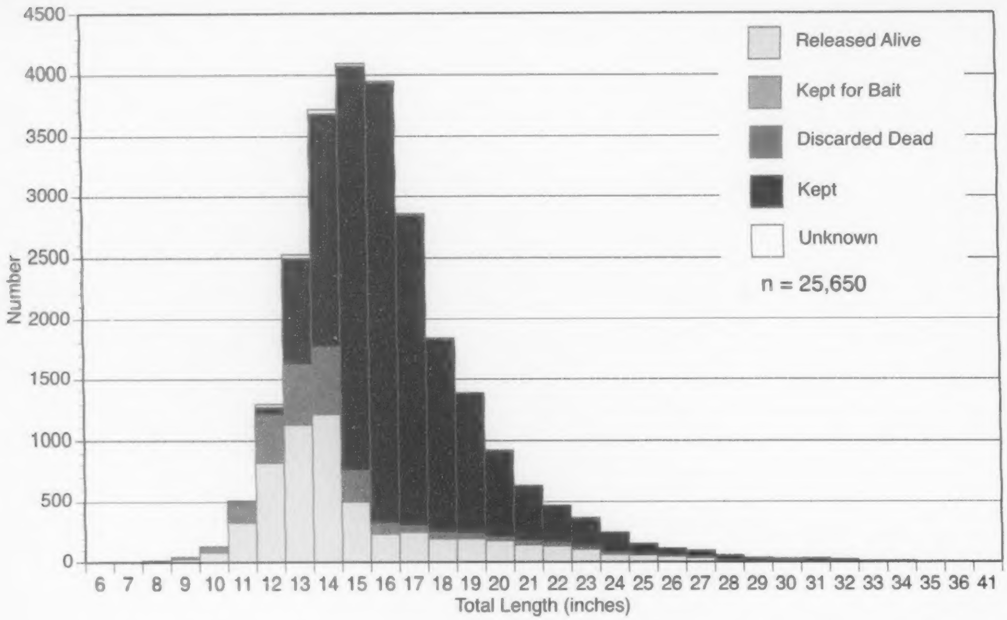

Figure 15.—Size and fate of red snapper caught on vertical line gear based on observer coverage of the U.S. Gulf of Mexico reef fish fishery from July 2006 through December 2009.

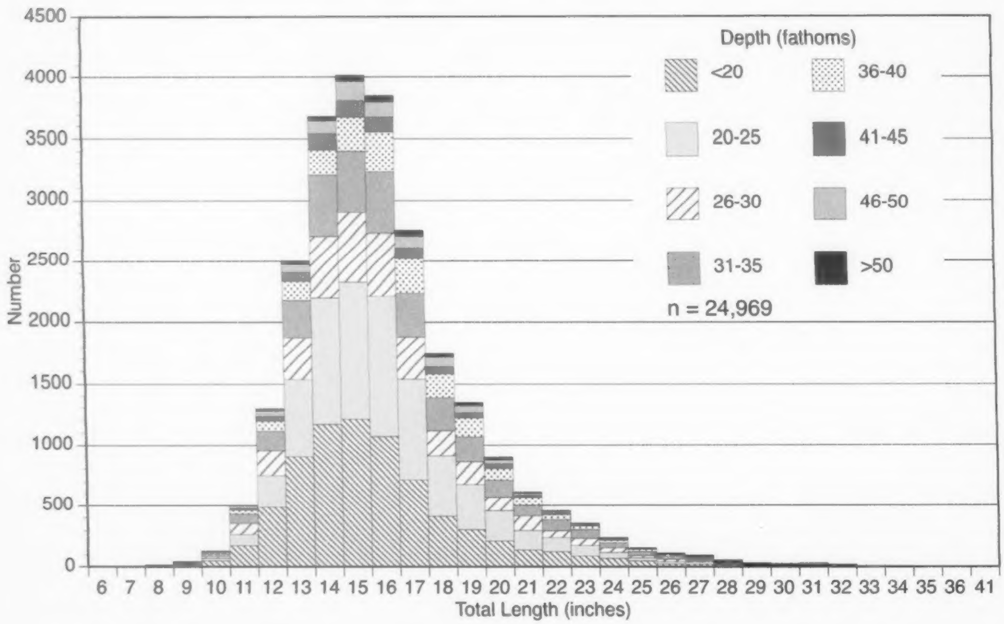

Figure 16.—Number of red snapper by size and depth zone caught on vertical line gear based on observer coverage of the U.S. Gulf of Mexico reef fish fishery from July 2006 through December 2009.

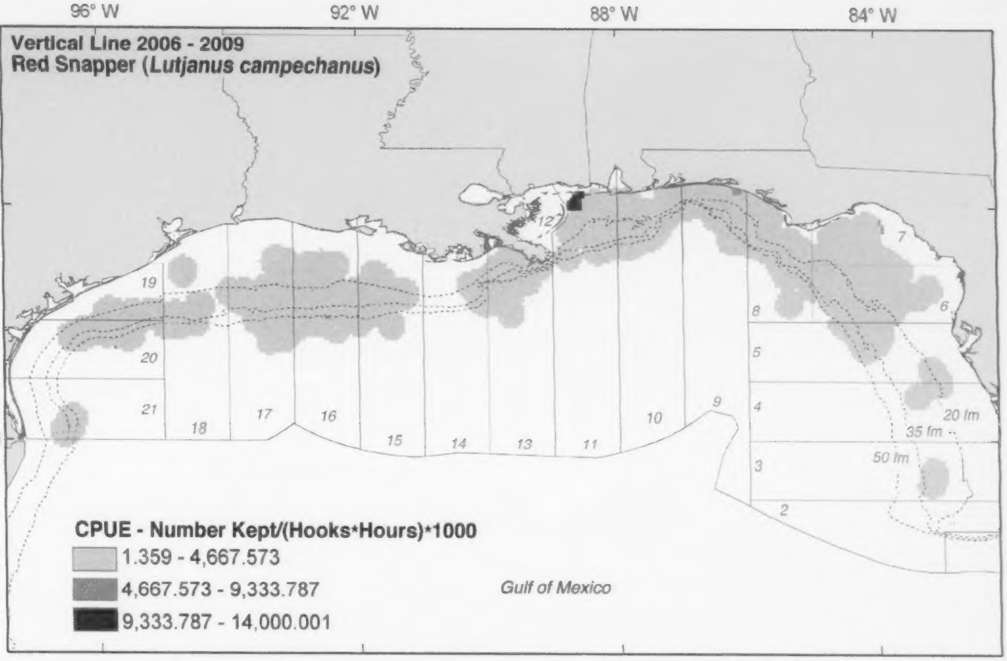

Figure 17.—CPUE density surface for red snapper kept in the vertical line fishery based on observer coverage of the U.S. Gulf of Mexico reef fish fishery from July 2006 through December 2009.

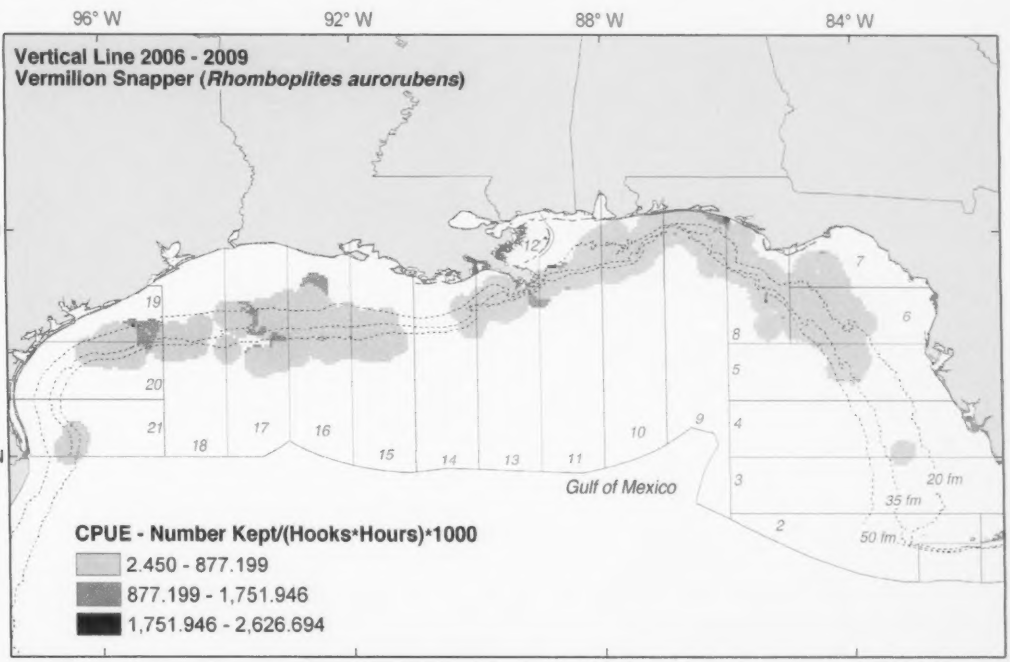

Figure 18.—CPUE density surface for vermilion snapper kept in the vertical line fishery based on observer coverage of the U.S. Gulf of Mexico reef fish fishery from July 2006 through December 2009.

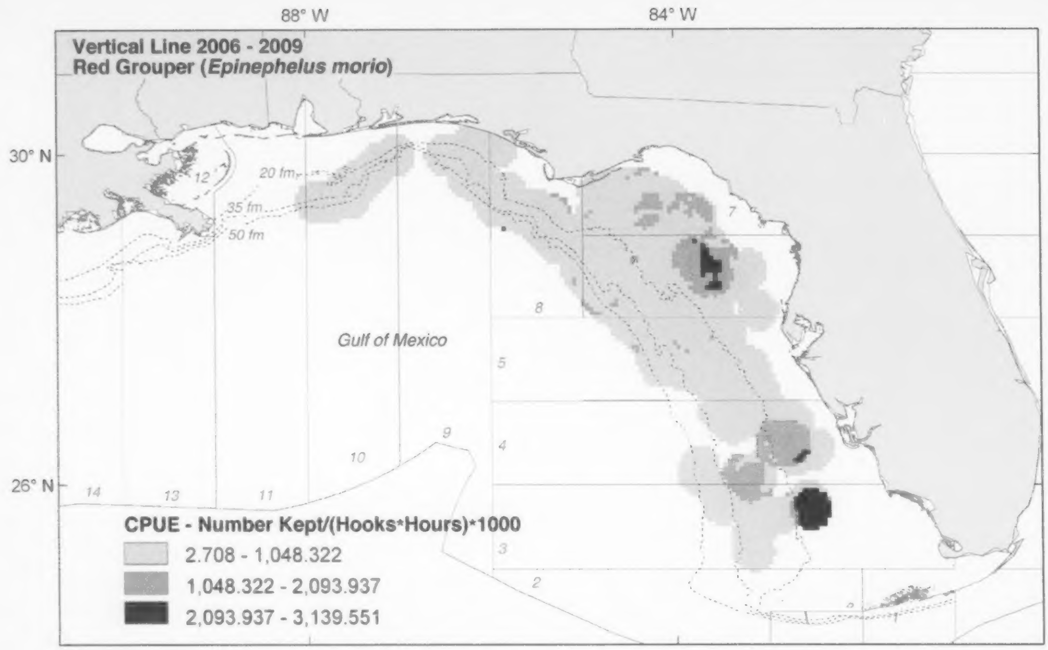

Figure 19.—CPUE density surface for red grouper kept in the vertical line fishery based on observer coverage of the U.S. Gulf of Mexico reef fish fishery from July 2006 through December 2009.

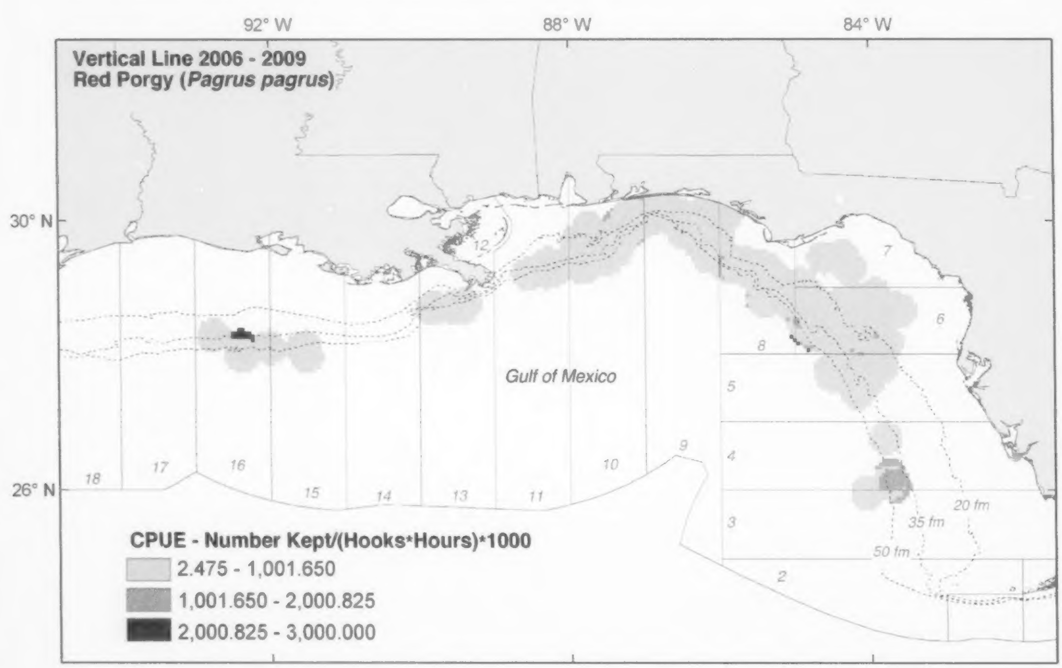

Figure 20.—CPUE density surface for red porgy kept in the vertical line fishery based on observer coverage of the U.S. Gulf of Mexico reef fish fishery from July 2006 through December 2009.

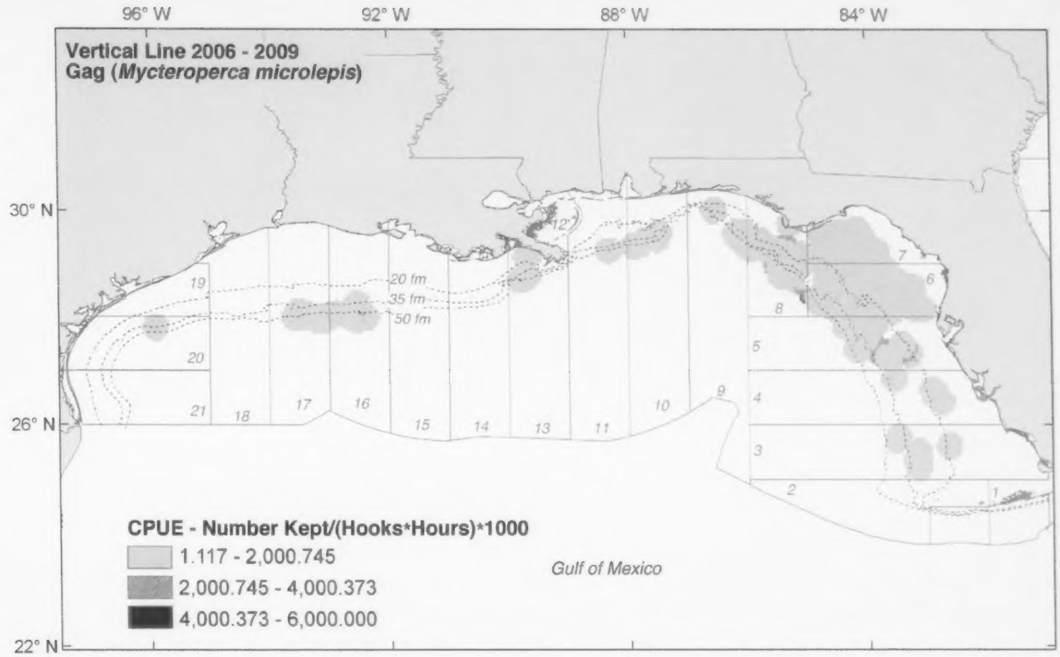

Figure 21.—CPUE density surface for gag kept in the vertical line fishery based on observer coverage of the U.S. Gulf of Mexico reef fish fishery from July 2006 through December 2009.

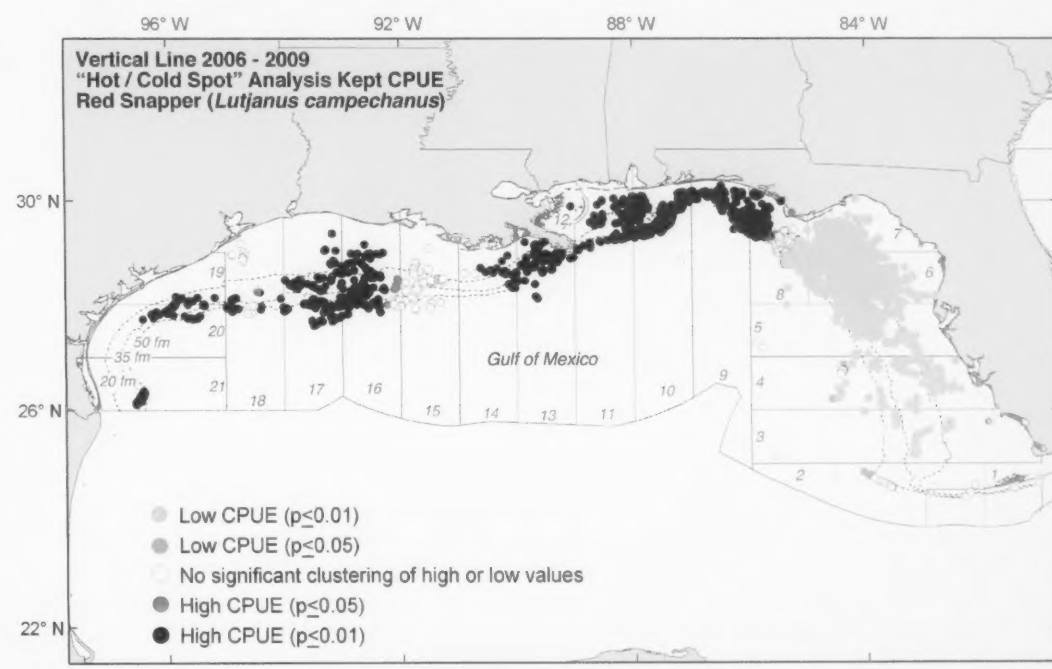

Figure 22.—Hot Spot Analysis for all kept red snapper in the vertical line fishery based on observer coverage of the U.S. Gulf of Mexico reef fish fishery from July 2006 through December 2009.

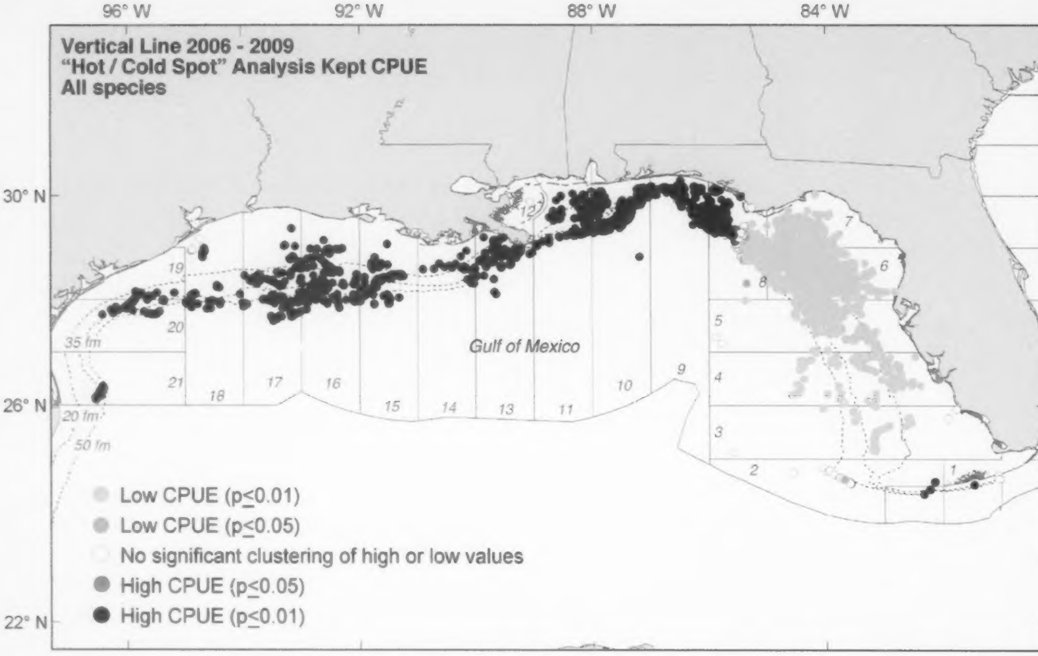

Figure 23.—Hot Spot Analysis for all kept species in the vertical line fishery based on observer coverage of the U.S. Gulf of Mexico reef fish fishery from July 2006 through December 2009.

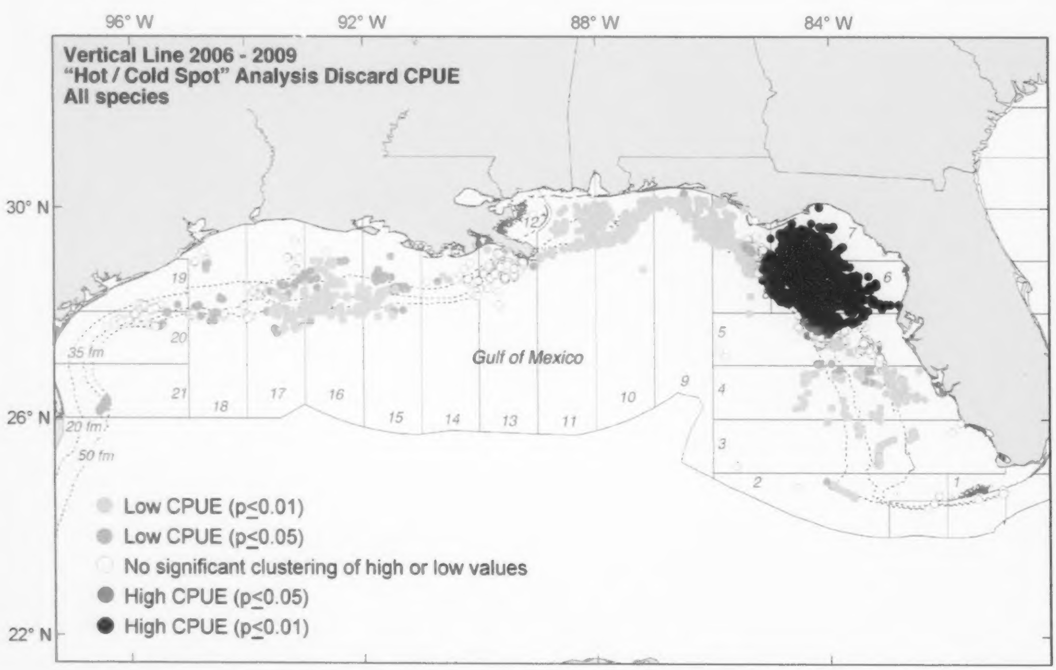

Figure 24.—Hot Spot Analysis for all discarded species in the vertical line fishery based on observer coverage of the U.S. Gulf of Mexico reef fish fishery from July 2006 through December 2009.

proportions may still adversely affect long-lived stocks.

Discard mortality rates are highly variable and influenced by a number of factors, including species-specific life history characteristics (Coleman et al., 2000; Patterson et al., 2002; Nieland et al., 2007), season (Render and Wilson, 1994) depth, and method of capture and release (Gitschlag and Renaud, 1994; Collins et al., 1999, Dorf, 2003; Rummer, 2007; Burns et al.[7]). Using the Marine Recreational Fishery Statistic Survey data from 1981–99 and findings from 53 release mortality studies, Bartholomew and Bohnsack (2005) found significant mortality factors related to hook location, bait removal, hook type, capture depth, water temperature, and handling time.

Through a tagging study conducted off the coast of Alabama, Patterson et al. (2002) indirectly estimated discard mortality of 13.5% for red snapper and <1% for gray triggerfish, based on surface release observations and recapture rates of fish caught with recreational gear. Red snapper (<18 in TL) comprised 93% of the released fish from a Texas headboat survey, of these 60.6% were released alive, 22.8% swam erratically, 15.2% floated, and 1.4% were discarded dead (Dorf, 2003). Diamond and Campbell (2009) examined red snapper caught on hook and line at three petroleum production platforms off south Texas and found immediate mortality at 17%; however, through the use of an injury status condition index, delayed mortality was estimated to be 64%.

Variable minimum assumed mortality rates and discard proportions may also be attributed to regulatory changes in minimum size limits and through implementation of IFQ requirements for several species, notably, red snapper, red grouper, and tilefish. Minimum assumed mortality (all discarded species combined) in this study was 24% in longline and 23% in vertical line. By species, immediate mortality for red grouper was 20% in longline and 11% in vertical line, with minimum assumed mortality for red snapper of 27% and 28%, in longline and in vertical line, respectively.

Table 9.—Coefficient of variation (CV) for Federally-managed discarded species caught aboard vertical line vessels in the Gulf of Mexico from July 2006 to December 2009.

Common name	Scientific name	*n*	CV
Red grouper	*Epinephelus morio*	6,597	<0.1
Red snapper	*Lutjanus campechanus*	19,227	<0.1
Vermilion snapper	*Rhomboplites aurorubens*	5,754	<0.1
Gag	*Mycteroperca microlepis*	1,096	<0.1
Greater amberjack	*Seriola dumerili*	621	<0.1
Lesser amberjack	*Seriola fasciata*	136	0.2
Gray triggerfish	*Balistes capriscus*	124	0.3
Warsaw grouper	*Epinephelus nigritus*	32	0.3
Snowy grouper	*Epinephelus niveatus*	32	0.3
King mackerel	*Scomberomorus cavalla*	20	0.3
Banded rudderfish	*Seriola zonata*	363	0.3
Scamp	*Mycteroperca phenax*	189	0.3
Cobia	*Rachycentron canadum*	24	0.3
Goliath grouper	*Epinephelus itajara*	12	0.4
Speckled hind	*Epinephelus drummondhayi*	24	0.4
Yellowedge grouper	*Epinephelus flavolimbatus*	28	0.4
Red drum	*Sciaenops ocellatus*	114	0.4
Lane snapper	*Lutjanus synagris*	79	0.4
Wenchman	*Pristipomoides aquilonaris*	52	0.4
Blueline tilefish	*Caulolatilus microps*	8	0.5
Red hind	*Epinephelus guttatus*	11	0.5
Rock hind	*Epinephelus adscensionis*	4	0.5
Yellowtail snapper	*Ocyurus chrysurus*	48	0.6
Gray snapper	*Lutjanus griseus*	49	0.6
Spanish mackerel	*Scomberomorus maculatus*	18	0.7
Black grouper	*Mycteroperca bonaci*	2	0.7
Queen snapper	*Etelis oculatus*	3	0.7
Silk snapper	*Lutjanus vivanus*	3	1.0
Tilefish	*Lopholatilus chamaeleonticeps*	1	1.0
Mutton snapper	*Lutjanus analis*	1	1.0
Yellowmouth grouper	*Mycteroperca interstitialis*	1	1.0

Stephen and Harris (2010) reported immediate mortality range of 33–100% for vertical line trips targeting vermilion snapper off South Carolina, with >90% mortality observed for gray triggerfish, greater amberjack, scamp, and red snapper. Nieland et al. (2007), using four release condition categories, similar but more detailed than that of this study, assessed the fate of red snapper regulatory discards aboard commercial vertical line vessels operating primarily off Louisiana and found 69% of discarded red snapper were either dying or dead when released.

Rudershausen et al. (2007) examined discard composition in the commercial snapper-grouper fishery in North Carolina and found low (<10%) immediate release morality for vermilion snapper, gag, and red grouper; moderate (14%) mortality for red porgy; and high (23%) immediate mortality for scamp.

In our study, red snapper ranged from 6–41 in TL with a mode of 15 in TL. Nieland et al. (2007), using specimens collected from commercial red snapper landings, described a similar unimodal distribution with the mode at 400 mm (15.7 in) TL, noting that 98% were less than 600 mm (23.6 in) TL. Red grouper length frequency data from NMFS bottom longline surveys in the Gulf of Mexico from 2000 through 2005 depicted a distribution range of approximately 10–34 in TL with a mode 18 in TL (Ingram et al.[19]); a similar range and mode as observed in this study.

Estimated CPUE for all species combined in the longline fishery was 0.0095 fish per hook-hour. Highest density CPUE (numbers of fish kept per 1,000 hook-hours) occurred in the eastern Gulf for red grouper and blueline tilefish, a similar distribution as reported by Ingram et al.[19] In deeper waters of the western Gulf, yellowedge grouper, tilefish, and scamp had high CPUE density values. For vertical line, the catch rate for all species was higher (0.0311 fish per hook-hour) than observed in longline. Highest CPUE for red snapper occurred in the western Gulf, consistent with SEDAR.[3] Density CPUE values

[19]Ingram, W., M. Grace, L. Lombardi-Carlson, and T. Henwood. 2006. Catch rates, distribution and size/age composition of red grouper, Epinephelus morio, collected during NOAA Fisheries Bottom Longline Surveys from the U.S. Gulf of Mexico. SEDAR-12-DW-05. Southeast Data Assessment and Review, South Atl. Fish. Manage. Counc., Charleston, SC (available at www.sefsc.noaa.gov/sedar/).

were higher and more dispersed in vertical line for other dominant species (vermilion snapper, red grouper, red porgy, and gag).

As prescribed by NMFS' National Bycatch Strategy addressing fishery bycatch on a national level, precision goals for bycatch estimates are defined in terms of CV estimates (NMFS, 2004). The precision of single species bycatch estimates is needed for population assessments; however, the reef fish fishery has bycatch from several stocks. In our study, CV estimates were low (0.1) for undersize target species, notably red grouper and red snapper. CV estimates for other species of commercial, recreational, and ecological importance, including several species of grouper and snapper, were relatively high and in some instances equal to 1.0.

In terms of areas of high bycatch, management measures to reduce bycatch should consider targets that include changes in fishing behaviors relative to avoidance of high bycatch areas, modifications of gear to reduce bycatch, and cooperative efforts to close areas with high bycatch. As illustrated by Hot/Cold Spot Analysis[15], areas of highly significant rates of discards were identified. In longline, discard CPUE density was significantly higher in statistical areas 3 through 6. For vertical line, discard catch rates were significantly higher and concentrated off Florida in statistical areas 5 through 7.

Prior to a mandatory observer program, self-reporting through logbook and discard supplementary data submission were used to estimate sea turtle take projections in the reef fish fishery and formed the basis of biological opinions pursuant to formal consultation under Section 7 of the ESA (NMFS[20]). Observers documented twenty sea turtle interactions, notably in the bottom longline component, during the study period (SEFSC[18]), resulting in important implications for management. In October 2009, a new biological opinion on the Gulf of Mexico reef fish fishery was completed with regulatory measures designed to minimize the impacts of future takes and monitor levels of incidental take (Fed. Regist.[21]).

Observer programs remain the most reliable means for monitoring fishery characteristics by not only providing insight on protected species interactions, but also for assessing quota and size restrictions, IFQ programs, CPUE, discard levels, gear effectiveness, and a wide array of other variables of interest to fishery managers, the fishing industry, academia, and the public.

[20]NMFS. 2005. Endangered Species Act–Section 7 consultation on the continued authorization of reef fish fishing under the Gulf of Mexico Reef Fish Fishery Management Plan and Proposed Amendment 23. Biol. Opinion. 15 Feb., 115 p. Southeast Reg. Off., Natl. Mar. Fish. Serv., NOAA, St. Petersburg, Fla. (available at http://sero.nmfs.gov/pr/pdf/Final_RFFMP23.pdf).

[21]Fed. Regist. 2009. Area closure and associated gear restrictions applicable to the bottom longline component of the Gulf of Mexico reef fish fishery. 74 FR 53890.

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We commend the outstanding efforts given by the fishery observers involved in this research effort and the commercial fishing industry. We sincerely thank Tim Baumer for the data entry system and summarization of data files.

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Simulation of Tail Weight Distributions in Biological Year 1986–2006 Landings of Brown Shrimp, *Farfantepenaeus aztecus*, from the Northern Gulf of Mexico Fishery

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ABSTRACT—Size distribution within reported landings is an important aspect of northern Gulf of Mexico penaeid shrimp stock assessments. It reflects shrimp population characteristics such as numerical abundance of various sizes, age structure, and vital rates (e.g. recruitment, growth, and mortality), as well as effects of fishing, fishing power, fishing practices, sampling, size-grading, etc.

The usual measure of shrimp size in archived landings data is count (C) *the number of shrimp tails (abdomen or edible portion) per pound (0.4536 kg). Shrimp are marketed and landings reported in pounds within tail count categories. Statistically, these count categories are count class intervals or bins with upper and lower limits expressed in* C. *Count categories vary in width, overlap, and frequency of occurrence within the landings. The upper and lower limits of most count class intervals can be transformed to lower and upper limits (respectively) of class intervals expressed in pounds per shrimp tail,* w, *the reciprocal of* C *(i.e.* w = 1/C*).*

Age based stock assessments have relied on various algorithms to estimate numbers of shrimp from pounds landed within count categories. These algorithms required underlying explicit or implicit assumptions about the distribution of C *or* w. *However, no attempts were made to assess the actual distribution of* C *or* w. *Therefore, validity of the algorithms and assumptions could not be determined. When different algorithms were applied to landings within the same size categories, they produced different estimates of numbers of shrimp.*

This paper demonstrates a method of simulating the distribution of w *in reported biological year landings of shrimp. We used, as examples, landings of brown shrimp,* Farfantepenaeus aztecus, *from the northern Gulf of Mexico fishery in biological years 1986–2006. Brown shrimp biological year,* T_i, *is defined as beginning on 1 May of the same calendar year as* T_i *and ending on 30 April of the next calendar year, where subscript* i *is the place marker for biological year. Biological year landings encompass most if not all of the brown shrimp life cycle and life span. Simulated distributions of* w *reflect all factors influencing sizes of brown shrimp in the landings within a given biological year. Our method does not require a priori assumptions about the parent distributions of* w *or* C, *and it takes into account the variability in width, overlap, and frequency of occurrence of count categories within the landings. Simulated biological year distributions of* w *can be transformed to equivalent distributions of* C.

Our method may be useful in future testing of previously applied algorithms and development of new estimators based on statistical estimation theory and the underlying distribution of w *or* C. *We also examine some applications of biological year distributions of* w, *and additional variables derived from them.*

Introduction

Size distribution within reported landings is an important aspect of northern Gulf of Mexico penaeid shrimp stock assessments. It reflects population characteristics such as numerical abundance of various sizes, age structure, and vital rates (e.g. recruitment, growth, and mortality), as well as effects of fishing, fishing power, fishing practices, sampling, size-grading, etc. (Kutkuhn, 1962; Neal, 1967; Rothschild and Brunenmeister, 1984; Nance et al., 1994; Diop et al., 2007; Caillouet et al., 2008; Nance et al., 2010; Parrack[1]; Nichols[2]). Age of shrimp cannot be determined directly (Parrack, 1979; Rothschild and Brunenmeister, 1984; Neal and Maris, 1985). Therefore, age structure of shrimp in reported landings has been determined indirectly by estimating numbers of shrimp from pounds allocated to marketing size categories, and transforming size into age using growth curves (Neal, 1967; Rothschild and Brunenmeister, 1984; Nance et al., 1994; Parrack[1]; Nichols[2]).

Most but not all reported landings from northern Gulf of Mexico shrimp fisheries are size-graded. The usual measure of shrimp size in archived landings data is count (*C*), the number of shrimp tails (abdomen or edible portion) per pound (0.4536 kg). Shrimp are marketed and landings reported in pounds within tail count categories. Statistically, these count categories are count class intervals or bins with upper and lower limits expressed in *C*. The upper and lower limits of most count class intervals

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[1]Parrack, M. L. 1981. Some aspects of brown shrimp exploitation in the northern Gulf of Mexico. Presented at the Workshop on the Scientific Basis for the Management of Penaeid Shrimp, Key West, Fla., Southeast Fisheries Science Center, National Marine Fisheries Service, NOAA, Miami, Fla. Unpubl. rep., 50 p.

[2]Nichols, S. 1984. Updated assessments of brown, white and pink shrimp in the U.S. Gulf of Mexico. Presented at the Workshop on Stock Assessment, Miami, Fla., Southeast Fisheries Science Center, National Marine Fisheries Service, NOAA, Miami, Fla. Upubl. rep., 54 p.

can be transformed to lower and upper limits (respectively) of class intervals expressed in pounds per shrimp tail, w, the reciprocal of C (i.e. $w = 1/C$)

Age based stock assessments have relied on various algorithms to estimate numbers of shrimp from pounds landed within count categories (e.g. Neal, 1967; Rothschild and Brunenmeister, 1984; Nance et al., 1994; Diop et al., 2007; Parrack[1]; Nichols[2]). These algorithms required underlying explicit or implicit assumptions about the distribution of C or w. However, no attempts were made to assess the actual distributions of C and w. Therefore, validity of the algorithms and assumptions could not be determined. When different algorithms were applied to landings within the same size categories (e.g. Parrack[1] vs. Nichols[2]), they produced different estimates of numbers of shrimp (Caillouet, 2003).

Estimating numbers of shrimp from pounds landed within size categories is statistically challenging for additional reasons. Some count categories representing the largest shrimp have an implied lower limit of zero (e.g. < 15 count), and some representing the smallest shrimp have an implied upper limit of ∞ (e.g. > 67 count). Neither zero nor ∞ can be transformed to real values of w. Count categories also exhibit considerable variability in width, overlap, and frequency of occurrence within the landings. Certain count categories dominate the landings, reflecting what are referred to as standard count categories: <15, 15–20, 21–25, 26–30, 31–40, 41–50, 51–67, and > 67 count (Caillouet et al., 2008).

This paper demonstrates a method of simulating the distribution of w in reported biological year landings of shrimp, as a basis for further investigation and evaluation of previously used algorithms and development of new ones. We used, as examples, landings of brown shrimp, *Farfantepenaeus aztecus*, from the northern Gulf of Mexico fishery in biological years 1986–2006. Neal (1967) defined brown shrimp biological year, T_i, as beginning 1 May of the same calendar year as T_i and ending 30 April of the next calendar year, where subscript i is the place marker for biological year (Table 1). Most landings in the i^{th} biological year are assumed to be produced from cohorts recruited to the fishery within that same biological year. In other words, a biological year encompasses most of the cycle and life span of brown shrimp within this intensive fishery.

Table 1.—Symbols and descriptions of variables used in analyses of biological year reported landings of brown shrimp from the northern Gulf of Mexico fishery. These apply only to size-graded landings in legitimate count categories; i.e. data selected by filtering, editing, and removing residual outliers from archived landings data.

Symbols	Descriptions of variables
T_i	biological year, from 1 May of a given calendar year through 30 April of the next calendar year, where $i = 0, \ldots, 20$ is the place marker for biological years 1986-2006
C_{ij}	the j^{th} lower limit of a legitimate count (number per pound) category in landings data from the i^{th} biological year, where $j = 0, \ldots, m_i$
m_i	the total number of C_{ij} in landings data from the i^{th} biological year
w_{ij}	the j^{th} upper limit of a pounds per shrimp tail category, where $w_{ij} = 1/C_{ij}$, in landings data from the i^{th} biological year
P_{ij}	the j^{th} cumulative proportion of pounds landed at w_{ij} in i^{th} biological year
q_{ij}	the j^{th} weighting factor for the P_{ij} and w_{ij} data pairs in the i^{th} biological year. This weighting factor, q_{ij}, is the sum of observations over all count categories having C_{ij} as their lower limit (or w_{ij} as their upper limit), regardless of the recorded upper limits of these count categories
w'_k	the k^{th} simulated value of weight per shrimp tail, where 0.005155 lb $\le w'_k \le$ 0.111111 lb, $k = 0, \ldots, 999$, and the interval between the w'_k is 0.000106
P'_{ik}	the k^{th} cumulative proportion of pounds landed at w'_k in the i^{th} biological year, which is simulated from the modified Richards function fitted to P_{ij} on w_{ij} in the i^{th} biological year
a_i	the parameter, estimated from the modified Richard's function fitted to P_{ij} on w_{ij} in the i^{th} biological year, which allows the w'_k at which $P'_{ik} = Pmax_i/2$ to vary among biological years
b_i	the parameter, estimated from the modified Richard's function fitted to P_{ij} on w_{ij} in the i^{th} biological year, which represents the maximum intrinsic rate of increase in P'_{ik} per unit w'_k at the inflection point of the curve
c_i	the parameter, estimated from the modified Richard's function fitted to P_{ij} on w_{ij} in the i^{th} biological year, which allows the sigmoid shape of the curve to vary (symmetrical or asymmetrical) among biological years
p'_{ik}	the k^{th} simulated proportion of pounds landed at w'_k in the i^{th} biological year
Y_i	the i^{th} biological year yield, which includes pounds of brown shrimp tails landed in legitimate count categories and in the unknown size category combined
f'_k	the k^{th} simulated number of shrimp tails at w'_k, where 0.005155 lb $\le w'_k \le$ 0.111111 lb, in the i^{th} biological year
N_i	the simulated total number of shrimp tails landed in the i^{th} biological year
$w50_i$	the simulated pounds per shrimp tail at which half of Y_i is harvested in the i^{th} biological year
N_i/Y_i	the simulated mean count of brown shrimp in the landings from the i^{th} biological year
Y_i/N_i	the simulated mean pounds per shrimp tail of brown shrimp in the landings from the i^{th} biological year

Our approach does not require a priori assumptions about the parent distributions of w or C, and it takes into account the variability in width, overlap, and frequency of occurrence of count categories within the landings. Simulated biological year distributions of w can easily be transformed to equivalent distributions of C. Our method may be useful in future testing of previously applied algorithms and development of new estimators based on statistical estimation theory and the underlying distribution of w or C. We also examine some applications of biological year distributions of w and additional variables derived from them.

Materials and Methods

Fishery

The brown shrimp fishery of the northern Gulf of Mexico is bounded by statistical subareas 10–21, and comprises inshore (estuarine) and offshore (Gulf of Mexico) territorial waters of Texas, Louisiana, Mississippi, Alabama, and a portion of Northwestern Florida, as well as adjoining Federal waters landward of the 50 fm depth contour within the U.S. Exclusive Economic Zone (EEZ) (Fig. 1). Brown shrimp produce annual crops (Neal and Maris, 1985), with recruitment to the fishery occurring in May–July (Rothschild and Brunenmeister, 1984). Although life span is 20–27 mo (Baxter, 1971), most brown shrimp are harvested within 6 mo of age.[3] Neal (1967)

[3]Fishery Management Plan for the Shrimp Fishery of the Gulf of Mexico, United States Waters. Gulf of Mexico Fishery Management Council, Tampa, Fla., Nov. 1981 (online at http://www.gulfcouncil.org).

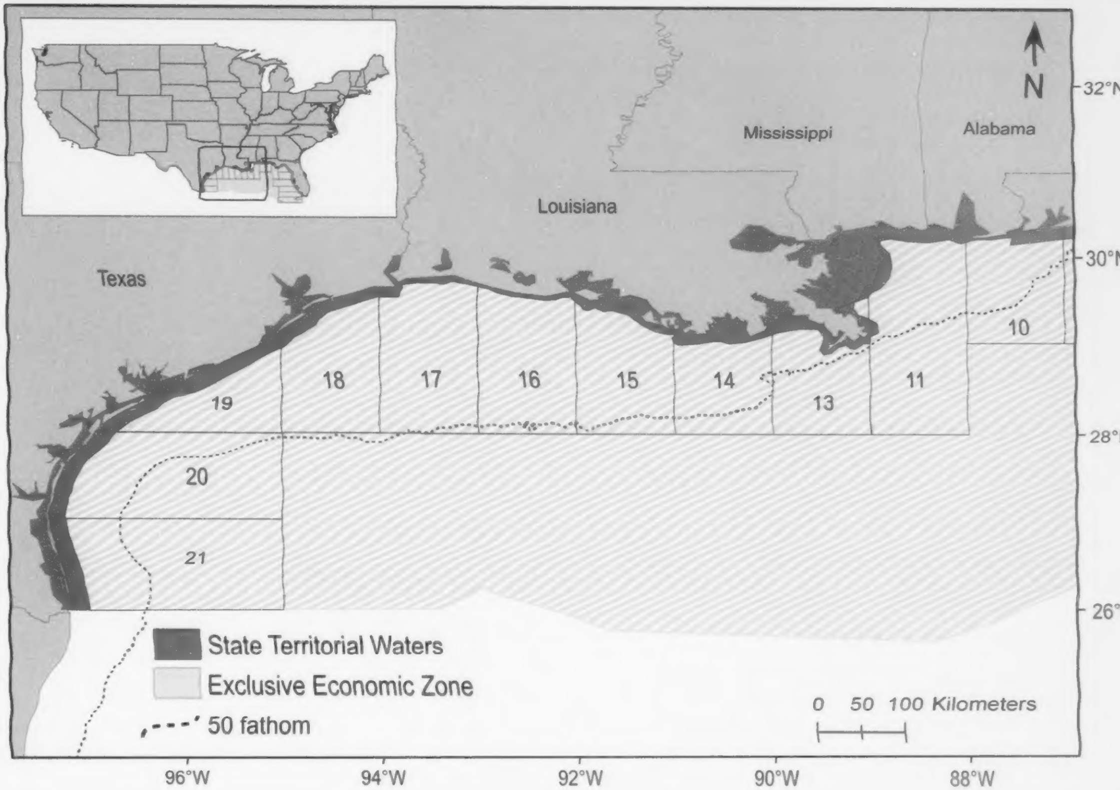

Figure 1.—Shrimp Statistical Subareas 10-21, encompassing the brown shrimp fishery within inshore (estuarine) and offshore (Gulf of Mexico) state territorial waters, and part (within the 50 fm depth contour) of the adjoining Federal EEZ in the northern Gulf of Mexico.

conducted virtual population analyses of brown shrimp in statistical subareas 18 and 19 (Fig. 1), and found that estimated numbers of brown shrimp in reported landings during biological year 1964 represented 97.7% of the total virtual population over a 17-mo period. This finding indicated that only 2.3% (by number) of the shrimp recruited as new cohorts in biological year 1964 contributed to the landings in biological year 1965. If shrimp landed in a given biological year within our time series (1986–2006) included survivors from cohorts recruited in preceding biological years, this could have affected our biological year simulations of w and other variables derived from them. However, such a carryover would be small, because it would involve only the larger sizes of shrimp which are lowest in pounds and fewest in numbers within the landings.

Landings Data

Brown shrimp landings data are archived by the National Marine Fisheries Service (NMFS) Galveston Laboratory, Texas. Statistically, reported landings are fishery-dependent samples taken without replacement from the brown shrimp population. They are multitudinous but have limitations (Kutkuhn, 1962; Snow, 1969; Prytherch, 1980; Parrack[1]; Nichols[2]; Poffenberger[4]) which may bias not only our simulated distributions of w and additional variables derived from them, but also may have biased previous estimates of numbers of shrimp from pounds landed within count categories. Not all brown shrimp that are caught are landed, and not all that are landed are reported (Kutkuhn, 1962; Berry and Benton, 1969; Baxter, 1973; Snow, 1969; Prytherch, 1980; Nance et al., 1991; Caillouet et al., 2008; Poffenberger[4]). Nonreported catch includes shrimp marketed directly to consumers, marketed as fishing bait (not all, but some), discarded for various reasons, kept for personal use by shrimpers, or otherwise not reported. Thus, reported landings are less than the actual catches, and also represent incomplete samples of the actual landings (Caillouet et al., 2008).

[4]Poffenberger, J. R. 1991. An overview of the data collection procedures for the shrimp fisheries in the Gulf of Mexico. National Marine Fisheries Service, Southeast Fisheries Science Center, Miami, Fla. (online at http://www.sefsc.noaa.gov/gssprogram.jsp).

Reported shrimp landings data are recorded by calendar year, month, statistical subarea (Fig. 1), depth zone, shrimping trip, and count category or unknown size category, along with other information (Kutkuhn, 1962; Snow, 1969; Prytherch, 1980; Poffenberger[4]). We treated the unknown size category as a catch-all category. In selecting records for a working file of size-graded landings data for our simulations, we excluded all landings originally reported in the unknown size category, as well as landings added to the unknown size category after we judged their count categories to be outliers (see Data Selection and Preparation below). The resultant unknown size category contained landings that were:

1) not size-graded,
2) size-graded incorrectly or size limits not recorded,
3) not assigned to a count category for other reasons (e.g. pieces of shrimp tails), or
4) size-graded but reported in count categories we judged to be outliers.

Previous investigators (e.g. Rothschild and Brunenmeister, 1984; Parrack[1]; Nichols[2]) also excluded certain landings from their analyses for various reasons. Two methods of grading shrimp, box-grading and machine grading, were described by Kutkuhn (1962), Snow (1969), Prytherch (1980), and Poffenberger[4]. Differences between these grading methods and variations in their relative contributions to size-graded landings over time may have biased our simulated distributions of w and variables derived from them, but they may also have biased previous estimates of numbers of shrimp within count categories.

Data Selection and Preparation

Our final working file contained archived landings records selected from biological years 1986–2006, but only those we considered to have legitimate count class limits. We initially consulted NMFS port agents (who collect landings data) to obtain their opinions about the true range in size of brown shrimp tails in the landings. It was agreed that the maximum C (smallest shrimp) for brown shrimp in the landings was around 250 tails per pound (equivalent to $w = 0.004$ lb, or 1.8 g), and minimum C (largest shrimp) around 9 tails per pound (equivalent to $w \approx 0.111$ lb, or ≈ 50.3 g).

Preparation of the working file involved filtering and editing a copy of archived data from biological years 1986–2006 as follows:

1) If a record was originally coded as belonging to the unknown category, it was excluded.
2) If an upper or lower limit of a count category was not recorded (i.e. left blank), the record was excluded.
3) If a recorded lower limit exceeded the recorded upper limit of a count category, the limits were assumed to have been inadvertently transposed at data entry, and the record was retained in the working file after being recoded by interchanging its count category limits.
4) If recorded upper and lower limits of a count category were both $C = 0$, the record was excluded.
5) If the recorded upper limit of a count category was $0 < C < 9$, both the lower and upper limits were recoded as $C = 9$, and the record was retained in the working file.
6) If only the recorded lower limit of a count category fell within $C < 9$, but the recorded upper limit was ≥ 9, the lower limit was recoded as $C = 9$, and the record was retained in the working file.
7) If the recorded lower and upper limits of a count category were $C > 250$, the record was excluded.
8) If the recorded upper limit of a count category was $C > 250$, but the recorded lower limit was $C \leq 250$, the upper limit was recoded as $C = 250$, and the record was retained in the working file.
9) All other archived records were retained in the working file.

We then performed statistical analyses of the working file to identify and remove records having count class limits we judged to be outliers. For each biological year, we used SYSTAT[5] to fit preliminary weighted linear regressions of upper limits on lower limits of the count categories, where the weighting factor was the number of observations (i.e. shrimping trips) associated with each unique count category (i.e. unique combination of upper and lower limits). Figure 2A is an example of a preliminary regression and data plot for biological

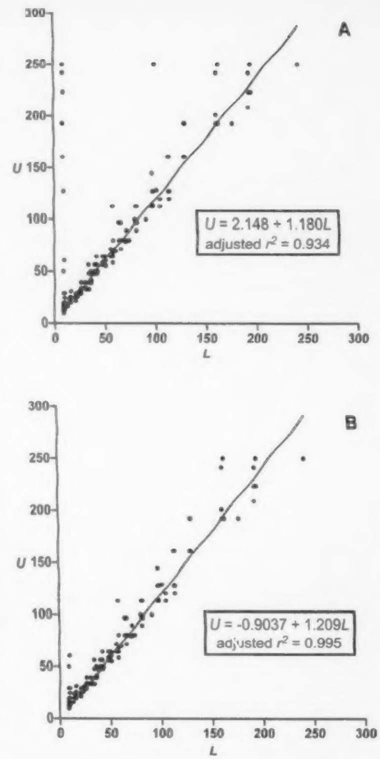

Figure 2.—Upper vs. lower limits of brown shrimp count categories in filtered and edited landings in biological year 2006; (A) before residual outlier records were removed and (B) after residual outlier records were removed. Lines were fitted by weighted linear regression, where the weighting factor was number of shrimping trips associated with each unique count category.

[5]Mention of trade names or commercial firms does not imply endorsement by the National Marine Fisheries Service, NOAA.

year 2006. Statistical weighting by number of shrimping trips was our way of dealing with variability in frequency of occurrence of count categories in the working file. Records removed from the working file by filtering, editing, and identification of residual outlier count categories represented a higher percentage of observations than percentage of pounds landed (Table 2); i.e. they contained relatively low pounds per observation.

We fitted final weighted linear regressions of upper limits on lower limits within the final working file for each biological year (Table 3). The weighting factor for these regressions was the number of observations (i.e. shrimping trips) associated with each unique count category remaining in the final working file. These final regressions characterized the relationship between legitimate count category upper and lower limits for each biological year. Figure 2B is an example final regression and data plot for biological year 2006. Slopes and intercepts of the final linear regressions (Table 3) for each biological year were examined for trends, using polynomial regression. Coded biological year (T_i − 1996) was substituted for T_i in these polynomial regressions, to avoid problems that otherwise might have been caused by correlations among powers of T_i (Sokal and Rohlf, 2000).

Aggregation and Cumulation of Landings

Landings from the final working file were aggregated (summed) by biological year and count category lower limits, C_{ij}, where j is the place marker for the C_{ij} within a biological year; $j = 0,\ldots, m_i$, where m_i is the total number of C_{ij} in each biological year (Table 1). Upper limits of count categories (equivalent to lower limits of class intervals of w) were ignored. Because the number of unique count categories in the final working file varied among biological years, the number of C_{ij} also varied among biological years, as did m_i. Summing the landings by biological year and C_{ij} produced a subset of data with much lower spatial-temporal resolution than that of more detailed data sets used in previous, bottom-up approaches to estimating numbers of shrimp within count categories (Neal, 1967; Rothschild and Brunenmeister, 1984; Nance et al., 1994; Diop et al., 2007; Parrack[1]; Nichols[2]).

Table 2.—Number of observations (shrimping trips) and pounds landed in the NMFS-archived records, compared to those remaining after filtering, editing, and removal of residual outlier count categories, for brown shrimp landings in the northern Gulf of Mexico fishery in biological years 1986–2006.

Records	Observations (shrimping trips)	Pounds (tails)
Archived	2,425,373 100.0%	1,682,806,769 100.0%
After filtering and editing	2,319,554 95.64%	1,668,305,100 99.14%
After residual outlier removal	2,308,674 95.19%	1,664,449,467 98.91%

Biological year summations of landings combined all spatial-temporal influences (statistical subarea, depth zone, and month) on size of brown shrimp in the landings. These influences included sex ratio, recruitment, growth, mortality, fishing effort, fishing power of shrimp trawlers, experience of captains and crews, gear selectivity, discarding, data collection procedures, grading methods, and possibly other factors that affect count category landings within a biological year. Spatial influences were collapsed to the level of the entire fishery, and temporal influences to the level of biological years. Summation of landings by C_{ij} combined landings within count categories having C_{ij} as their lower limit. The simple hypothetical example below depicts this process:

Count Category	Observations	Pounds landed
9–12	2	500
9–15	3	1,200
9–20	1	40
Total	6	1,740

The sum of observations over all count categories having C_{ij} as their lower limit became the weighting factor, q_{ij}, for each C_{ij} and the sum of pounds associated with it. In the hypothetical example above, $C_{ij} = 9$, $q_{ij} = 6$, and both are associated with 1,740 lb landed.

Table 3.—Final weighted linear regressions of upper (U) on lower (L) limits of count categories in brown shrimp landings data selected by filtering, editing, and removal of residual outliers from the NMFS-archived landings data. The weighting factor was the number of shrimping trips associated with each unique count category (i.e. unique U and L data pair) in the landings data selected from each biological year. Sample size was the sum of these weighting factors for each biological year (see Fig. 2).

Biological year, T_i	Intercept$_i$	Slope$_i$	Sample size	Adjusted r_i^2
1986	−0.0609420	1.172878	141,523	0.988
1987	−0.7467180	1.189633	159,010	0.988
1988	0.4795405	1.160103	158,733	0.992
1989	0.0479237	1.171595	147,315	0.992
1990	0.6609263	1.157006	137,647	0.993
1991	−0.1564869	1.180132	122,065	0.992
1992	0.1879865	1.169404	117,633	0.991
1993	−0.5079871	1.187639	105,907	0.989
1994	0.0533226	1.173414	111,968	0.992
1995	−0.1264397	1.179191	102,643	0.993
1996	−0.7873293	1.195364	97,111	0.989
1997	−1.4422680	1.210573	98,415	0.987
1998	−1.0609130	1.199557	91,378	0.988
1999	−1.2453040	1.204808	92,638	0.985
2000	−0.3466840	1.179789	95,775	0.990
2001	0.1584804	1.169094	89,022	0.992
2002	−0.2696291	1.187891	122,160	0.992
2003	−1.0236740	1.206445	103,013	0.993
2004	−1.1202140	1.208740	82,006	0.993
2005	−0.3479283	1.192750	69,662	0.994
2006	−0.9036610	1.208740	63,050	0.995

Examples of variation in C_{ij} and q_{ij} for biological years 1986, 1996, and 2006 are shown in Figure 3. Dominant C_{ij} were conspicuous as indicated by their q_{ij}, and many were identical or close to the C_{ij} of standard count categories, as expected.

Within each biological year, the pounds associated with C_{ij} were cumulated over the observed range of C_{ij}, from the highest to the lowest C_{ij} (i.e. from the smallest to largest shrimp tails). These cumulative pounds were then converted to proportions of cumulative pounds landed, P_{ij} (Table 1), from the highest to the lowest C_{ij}. Figure 4A is an example of the stair-stepped relationship between P_{ij} and C_{ij} for biological year 2006, and Figure 4B is the equivalent stair-stepped relationship between P_{ij} and w_{ij}, where $w_{ij} = 1/C_{ij}$.

Modified Richards Function

We searched for an asymptotic, asymmetrical sigmoid regression model to convert the stair-stepped relationship between P_{ij} and w_{ij} to a smooth curve for each biological year. The regression model we chose was a simplified form of the Richards function (Richards, 1959):

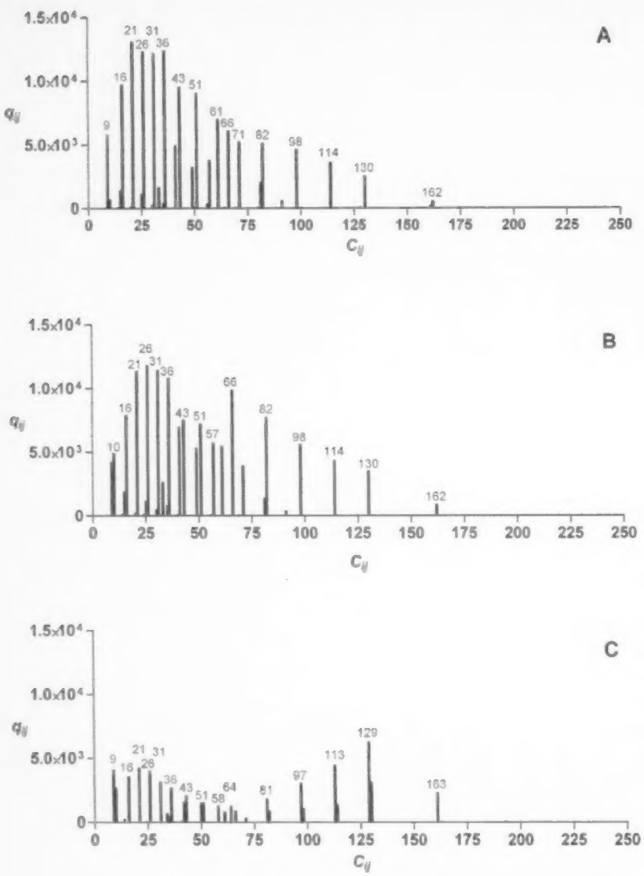

Figure 3.—Weighting factors, q_{ij} (i.e. shrimping trips) vs. legitimate brown shrimp count category lower limits, C_{ij}, for biological years (A) 1986, (B) 1996, and (C) 2006. Dominant C_{ij} are marked by the numbers above vertical bars representing their q_{ij}.

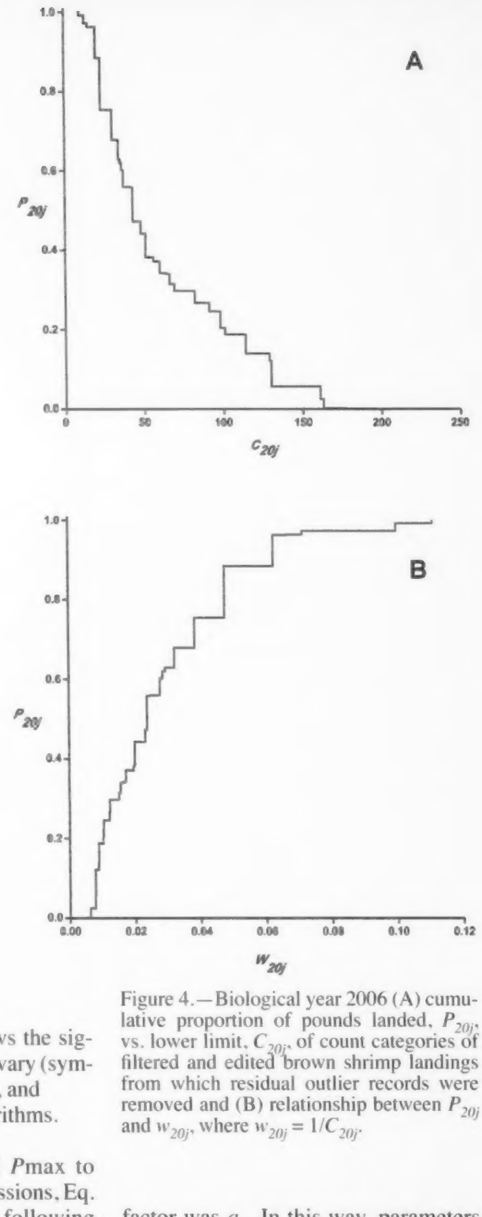

Figure 4.—Biological year 2006 (A) cumulative proportion of pounds landed, P_{20j}, vs. lower limit, C_{20j}, of count categories of filtered and edited brown shrimp landings from which residual outlier records were removed and (B) relationship between P_{20j} and w_{20j}, where $w_{20j} = 1/C_{20j}$.

$$P = P\max\left(1-e^{a-bw}\right)^{c} \qquad (1)$$

where, P is the cumulative proportion of pounds landed at w,

w is shrimp tail weight in pounds, over the observed range from minimum to maximum w,

Pmax is the upper asymptote,

a is the parameter which allows w at which $P = P\max/2$ to vary,

b is the parameter which represents the maximum intrinsic rate of increase in P per unit w, which occurs at the inflection point on the curve,

c is the parameter that allows the sigmoid shape of the curve to vary (symmetrical or asymmetrical), and

e is the base of natural logarithms.

Because we constrained Pmax to equal 1 in fitting all the regressions, Eq. (1) was simplified into the following regression model:

$$P = \left(1-e^{a-bw}\right)^{c}. \qquad (2)$$

For each biological year, we used GraphPad Prism (version 5.02) to fit Eq. (2) to P_{ij} on w_{ij} by weighted nonlinear regression, where the weighting factor was q_{ij}. In this way, parameters a_i, b_i, and c_i (Table 1) were estimated for each biological year (Table 4). The lower case parameter c_i should not be confused with the upper case count C_{ij}. We tried fitting a number of other asymmetrical sigmoid functions available in GraphPad Prism, but Eq. (2) was the best fitting of those we examined. While

we recognize that additional curve fitting methods and models could have been tested, Eq. (2) was adequate for purposes of demonstrating our simulation approach. By fitting Eq. (2), we smoothed the relationship between P_{ij} on w_{ij}, and obtained an equation representing this relationship for each biological year (Table 4). We also calculated the adjusted r^2 as an approximation of how well Eq. (2) fit the data points for each biological year (Table 4), but recognize it is not strictly applicable to nonlinear regression.

Table 4.—Biological year yield (Y_i), parameter estimates, and other statistics for weighted nonlinear regressions (modified Richards function, Eq. (2)) of cumulative proportions of pounds landed, P_{ij}, on pounds per shrimp tail, w_{ij}, in brown shrimp landings data selected by filtering, editing, and removal of residual outliers from the NMFS-archived landings data. The weighting factor was the number of shrimping trips, q_{ij}, associated with each data pair, P_{ij} and w_{ij}, in the selected landings data. For a given biological year, the number of data points analyzed (total sample size) was the sum of these weighting factors, $\sum_{j=0}^{m_i} q_{ij}$.

Biological year, T_i	Yield Y_i, pounds	Estimated parameters a_i	b_i	c_i	Total sample size $\sum_{j=0}^{m_i} q_{ij}$	Adjusted r_i^2
1986	94,738,424	0.2770842	53.75477	1.016937	141,523	0.994
1987	89,394,421	0.3177634	61.64658	1.074417	159,010	0.997
1988	79,859,436	0.2713897	57.15293	1.286208	158,733	0.997
1989	94,170,525	0.2802385	58.89570	1.243767	147,315	0.996
1990	105,121,282	0.2865627	55.59358	0.968642	137,647	0.992
1991	85,602,708	0.1627544	47.08183	1.095961	122,065	0.993
1992	68,425,417	0.2294646	55.76027	1.150789	117,633	0.995
1993	66,431,237	0.2427682	55.10823	0.865503	105,907	0.989
1994	67,049,354	0.2126820	51.46945	1.107677	111,968	0.996
1995	75,859,021	0.2123855	48.21137	0.829590	102,643	0.991
1996	73,500,416	0.2459783	55.83692	0.888528	97,111	0.991
1997	65,389,618	0.2837078	55.32308	0.761172	98,415	0.994
1998	80,514,861	0.2723718	61.82822	0.975136	91,378	0.992
1999	81,035,496	0.2308989	56.10879	0.836558	92,638	0.987
2000	94,463,851	0.3038908	59.25881	1.084649	95,775	0.995
2001	87,660,251	0.3287329	74.62214	1.352838	89,022	0.987
2002	73,180,653	0.3917993	81.88587	1.447248	122,160	0.988
2003	82,309,001	0.3194503	79.86258	1.376817	103,013	0.986
2004	74,233,767	0.2973424	57.98183	0.884165	82,006	0.981
2005	58,819,403	0.2349768	56.86499	1.169126	69,662	0.981
2006	85,047,627	0.0818478	51.68214	1.640370	63,050	0.991

Simulating Biological Year Distribution of Tail Weight

The next step toward simulating the distribution of w was to generate a new set of data pairs for each biological year, using the fitted equations in Table 4. First, we generated equally spaced values of w'_k (Table 1), from a minimum, w'_0 (= 0.005155 lb), to a maximum, w'_{999} (=0.111111 lb), where the k^{th} place marker for the w'_k was $k = 0, \ldots, 999$ (Table 1). The increment, g, between the w'_k was then calculated as

$$g = \left(w'_{999} - w'_0\right)/999$$
$$= 0.000106 \text{ lb.}$$

The w'_k were generated by

$$w'_k = k(g) + w'_0.$$

We then generated values of P'_{ik} for each w'_k for each biological year, using the following equation and estimates of parameters a_i, b_i, and c_i from Table 4:

$$P'_{ik} = \left(1 - e^{a_i - b_i w'_k}\right)^{c_i}. \qquad (3)$$

Three reasons for applying w'_0 = 0.005155 lb (derived from 1/194) as the minimum shrimp tail weight for all biological year simulations were:

1) The lowest maximum C_{ij} observed (in the working file) among all biological years was 194 count, the reciprocal of the highest minimum w_{ij}.
2) Imaginary numbers were generated by Eq. (3) for the minimum P'_{ik} in some biological years when the actual minimum w_{ij} observed in those years was applied (this probably was due in part to the fact that Eq. (3) did not fit the data points representing very small shrimp tails closely in those years).
3) It was consistent to constrain w'_k to be the same for all biological years.

The first derivative of Eq. (3), $\delta P'_{ik}/\delta'_{wk}$, was

$$\delta P'_{ik}/\delta w'_k = b_i c_i \left(1 - e^{a_i - b_i w'_k}\right)^{c_i - 1} \left(e^{a_i - b_i w'_k}\right). \quad (4)$$

For each biological year, we used Eq. (4) to generate first derivatives for each w'_k. To transform these first derivatives (Eq. (4)) into p'_{ik} (Table 1), which was the proportion of pounds landed at w'_k for each biological year, we divided them by the sum of all first derivatives over the range in w'_k, for each biological year. This sum was calculated as

$$\sum_{k=0}^{999} \left(\delta P'_{ik}/\delta w'_k\right).$$

In other words, for each biological year, p'_{ik} at each w'_k was calculated as

$$p'_{ik} = \left(\delta P'_{ik}/\delta w'_k\right) \Big/ \sum_{k=0}^{999} \left(\delta P'_{ik}/\delta w'_k\right).$$

Biological year yield, Y_i, encompassed all landings within a biological year, including those retained in our final working file as well as those that had been excluded from it. For each biological year, number of shrimp tails, f'_{ik} (Table 1), at each w'_k was calculated by

$$f'_{ik} = Y_i \left(p'_{ik}\right)/w'_k. \qquad (5)$$

Equation 5, describing the relationship between f'_{ik} and w'_k, is the simulated distribution of w for the i^{th} biological year.

We would have been able to exclude some steps in our simulation sequence had the final working file represented total reported landings from each biological year (i.e. Y_i). However, the final working file was a subset of size-graded landings selected from the archived landings, and it did not contain landings we excluded (i.e. those relegated to the unknown category), whereas Y_i contained all landings for each biological year. Therefore, Eq. (5) applied the subset of proportions p'_{ik} to

the total yield Y_i to estimate f'_{ik} for each biological year.

We recognize that relative distributions of w for each biological year, and their corresponding cumulative relative distributions, also could have been derived from our simulated distributions of w. They might be of interest in some applications of our approach, but they were not essential to the purpose of our paper. They can easily be calculated from the information provided in this paper. However, the concept of cumulative relative distribution of w in biological year landings of brown shrimp is important in that it would estimate the probability of occurrence of tail weight $\leq w$; i.e. it would be an approximation of the cumulative distribution function (CDF) for w. This is the major part of the explanation of why we chose lower limits, C_{ij} (equivalent to upper limits of w_{ij}), for aggregating and cumulating landings, and then transformed C_{ij} to w_{ij} in preparation for fitting Eq. (2). Because a simulated distribution of w can be used to calculate the relative distribution of w and cumulative relative distribution of w, it is relevant to future testing of past algorithms and development of new ones to estimate numbers of shrimp from pounds landed within class intervals of w or C in the landings. Although we excluded certain landings (unknown size category) and ignored upper limits of legitimate count categories in simulating biological year p'_{ik}, our simulations of f'_{ik} included all biological year landings (Y_i); i.e. all biological year landings contributed to simulation of biological year distributions of w.

Biological Year Total Number of Shrimp Tails (N_i), Mean C_i, and Mean w_i

The total number of shrimp tails, N_i, in the landings from a biological year T_i was simulated by

$$N_i = \sum_{k=0}^{999} f'_{ik}. \qquad (6)$$

Crude estimates of biological year mean count (N_i/Y_i) and its equivalent mean tail weight (Y_i/N_i) were calculated. We examined trends in both of these means via polynomial regression, where coded years (T_i – 1996) were substituted for T_i.

Tail Weight at Half of Y_i

Given that a fitted equation representing the relationship between P_{ij} and w_{ij} was available for each biological year (Table 4), we estimated tail weight, $w50_i$, at which half of the annual yield, $Y_i/2$, was harvested in each biological year (note that when Pmax is constrained to equal 1, $w50_i = P\text{max}/2 = 0.5$). Each equation (Table 4) was solved for $w50_i$ as follows:

$$w50_i = \left[a_i - \ln\left(1 - 0.5^{1/c_i}\right)\right] / b_i.$$

This statistic is similar in concept to *LD50*, the estimated lethal dose (concentration) of a toxic substance at which 50% mortality occurs in exposed subjects. In our application, it is a potentially useful index of the relationship between brown shrimp size and yield (see Caillouet et al., 2008). We examined $w50_i$ via polynomial regression, where coded years (T_i – 1996) were substituted for T_i.

Results

Polynomial Regressions

We recognize that polynomial regression is an empirical approach to fitting a curve to a time series of data, and that the resulting polynomial terms have no structural meaning (Sokal and Rohlf, 2000). We applied it only to detect possible trends in the variables we simulated, and to demonstrate possible applications of our simulated distributions of w. Obviously, many other curve fitting approaches could have been used to examine the time series for each variable. Causes and effects within this brown shrimp fishery could have influenced the detected polynomial trends, despite variability (deviations from regression) caused by fluctuations in annual recruitment and other factors which are typical in shrimp populations (Caillouet et al., 2008).

Weighted Linear Regressions of Upper vs. Lower Limits of Count Categories

Data plots and preliminary weighted linear regressions of upper on lower limits of unique count categories in each biological year (see the example for the year 2006 in Fig. 2A) showed that count category outliers remained in the data after filtering and editing. In the year 2006 example, the outliers were concentrated near the minimum lower limit count of 9 (largest shrimp), which elevated the intercept of the fitted line in Figure 2A as compared to the intercept of the fitted line in Figure 2B, in which residual outliers had been removed. The unusually wide class intervals of outlier count categories could lead to serious biases in estimating numbers of shrimp within such count categories. Also, we emphasize that each data pair (upper and lower limits) was weighted, so the actual numbers of residual outliers are much higher than the number of data points representing outliers in Figure 2A (Table 2).

As expected, final weighted linear regressions of upper limits on lower limits of count categories were close fitting in all biological years as shown by high adjusted r^2 (Table 3, Fig. 2B). These final regressions characterized the relationship between upper and lower limits of what we considered to be legitimate count categories in each biological year. All slopes of these final regressions were slightly greater than 1 (Table 3), indicating that count class intervals in the working file widened as their lower limits increased. Trends in slopes and intercepts of these regressions are shown in Figures 5A and 5B, respectively.

Biological Year m_i and Weighted Regressions of P_{ij} on w_{ij}

The biological year total number, m_i, of C_{ij} exhibited a concave quadratic (parabolic) trend (Fig. 6); m_i dropped from 77 in 1986 to 35 in 1995, then increased but not to its earlier highest level. This trend in m_i reflected changes in the total number of legitimate

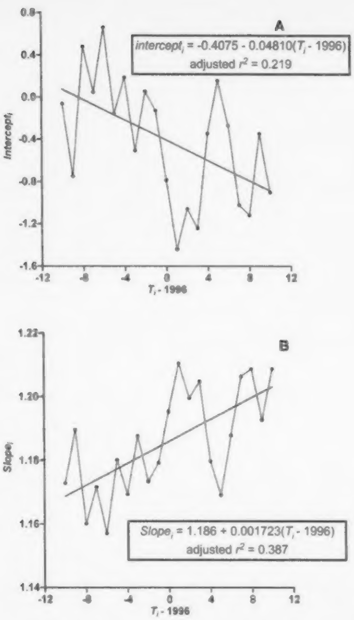

Figure 5.—Linear trends in (A) intercepts and (B) slopes of final weighted linear regressions of upper limits on lower limits of legitimate brown shrimp count categories, over coded biological years (T_i – 1996).

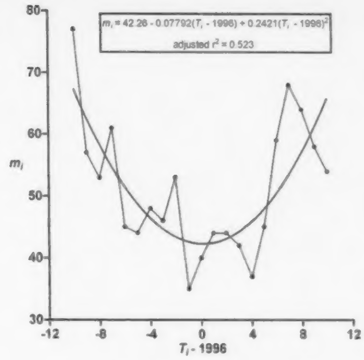

Figure 6.—Quadratic trend in total number, m_i, of count category lower limits, C_{ij}, for filtered and edited brown shrimp landings from which residual outlier count categories were removed, over coded biological years (T_i – 1996).

count categories over the biological years. However, the total number of count categories in biological year T_i exceeds m_i, because upper limits of count categories were ignored in our simulations; i.e. landings at the count category level were combined at the count category lower limit level, C_{ij} (see Aggregation and Cumulation of Landings). Wide variation in biological year numbers of count categories and the consequential quadratic trend in m_i (Fig. 6) are interesting and worthy of further investigation. They could reflect changes in size-related marketing strategies, recruitment, and perhaps other influences on choices of count categories in the landings.

Weighted nonlinear regressions of P_{ij} on w_{ij} for all biological years were close fitting, as indicated by very high adjusted r_i^2 (Table 4). Over all biological years, adjusted r_i^2 equaled or exceeded 0.981. Examples of plotted data points P_{ij} vs. w_{ij} and fitted curves for 1986, 1996, and 2006 are shown in Figures 7A–C, respectively. Inflection points of the regressions were far to the lower left in such plots (Fig. 7A–C), suggesting that brown shrimp were fully recruited to the landings at very small sizes, which is a very important finding.

The total sample size,

$$\sum_{j=0}^{m_i} q_{ij}$$

(Fig. 8), for each biological year regression (Table 4), and the adjusted r_i^2 (Fig. 9) for these regressions, declined over biological years. In other words, adjusted r_i^2 and total sample size were dependent, as expected (Fig. 10); i.e. the larger the sample size the higher the adjusted r_i^2. We emphasize that the total sample size (Fig. 8) used in fitting the regressions of P_{ij} on w_{ij} for each biological year was less than the actual number of shrimping trips in the archived data for each biological year, because landings from some trips were initially in the unknown category or later placed there by filtering, editing, and outlier removal from the working file. Therefore, the data points and trend in Figure 8 should not be taken to represent total shrimping trips in the biological years.

As is common in fitting models containing more than one parameter, the parameter estimates often are not independent (i.e. orthogonal). Graph-

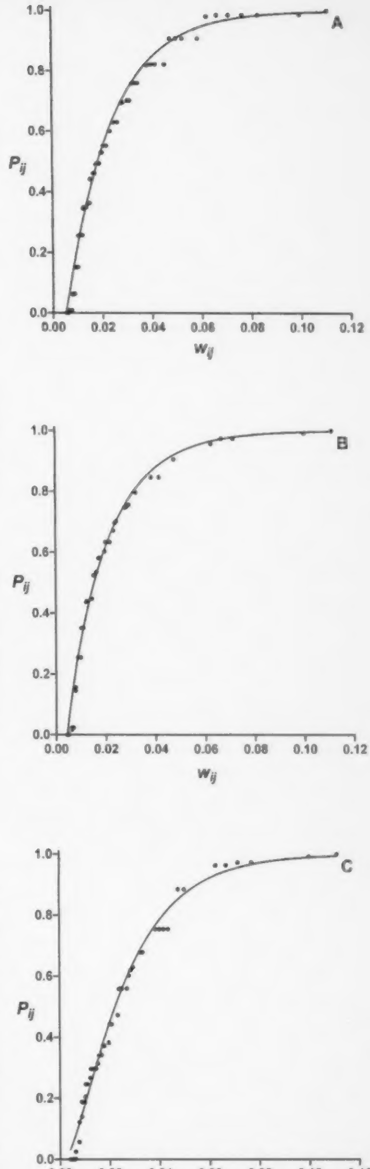

Figure 7.—Weighted nonlinear regressions (modified Richards function) fitted to cumulative proportion of brown shrimp landings, P_{ij}, vs. pounds per shrimp tail, w_{ij}, for biological years (A) 1986, (B) 1996, and (C) 2006.

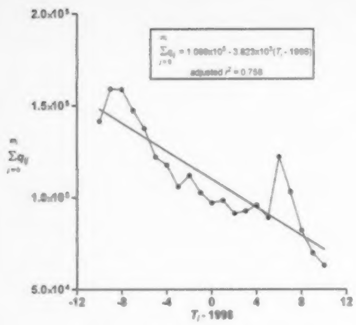

Figure 8.—Linear trend in annual shrimping trips,

$$\sum_{j=0}^{m_i} q_{ij} ,$$

over coded biological years (T_i – 1996), for brown shrimp landings in legitimate count categories.

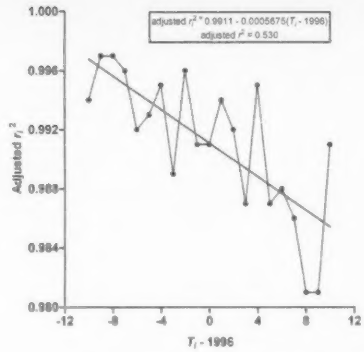

Figure 9.—Linear trend in adjusted r_i^2 for weighted nonlinear regressions (modified Richards function) fitted to cumulative proportion of brown shrimp landings, P_{ij}, vs. pounds per shrimp tail, w_{ij}, over coded biological years (T_i – 1996).

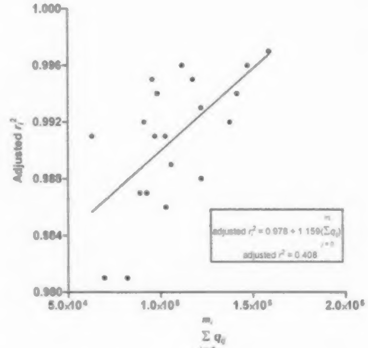

Figure 10.—Linear relationship between adjusted r_i^2 and annual shrimping trips,

$$\sum_{j=0}^{m_i} q_{ij} ,$$

for weighted nonlinear regressions (modified Richards function) fitted to cumulative proportion of brown shrimp landings, P_{ij}, vs. pounds per shrimp tail, w_{ij}.

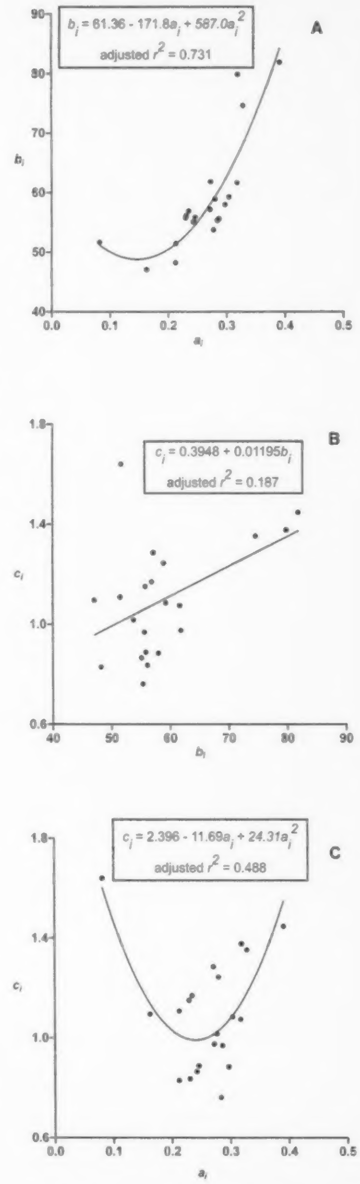

Figure 11.—(A) Quadratic relationship between parameters b_i and a_i, (B) linear relationship between parameters c_i and b_i, and (C) quadratic relationship between parameters c_i and a_i, for weighted nonlinear regressions (modified Richards function) fitted to cumulative proportion of brown shrimp landings, P_{ij}, vs. pounds per shrimp tail, w_{ij}.

Pad Prism provided estimates of dependency of estimated parameters a_i, b_i, and c_i within each biological year regression (dependency = 1 represents complete dependency, and dependency = 0 indicates orthogonality). Over biological years, dependency was 0.865–0.985 for parameter a_i, 0.968–0.981 for parameter b_i, and 0.978–0.994 for parameter c_i. Not only did all these parameters show strong dependency within each biological year regression, but they also appeared related to each other over biological years (Fig. 11A–C).

Simulated Distributions of *w*

Example distributions of w'_k for biological years 1986, 1996, and 2006 are shown in Figures 12A–C. All were strongly skewed to the right. Their most striking feature was their likeness to negative exponential curves. Therefore, we plotted them in the form of $\ln(f'_{ik})$ vs. w'_k for all biological years (Fig. 13). Straight lines for $\ln(f'_{ik})$ vs. w'_k would have indicated that these simulated distributions of w followed a negative exponential pattern, once full recruitment to the landings was reached at very small sizes (Fig. 13). Only slight concavity was evident in all the curves.

Biological Year Total Number of Shrimp Tails and Yield

Interestingly, although the biological year total number of shrimp tails, N_i (Fig. 14), and yield, Y_i (Fig. 15), showed hints of declines, they exhibited no significant trends over biological years, because of wide year to year variation. A close linear relationship between N_i and

Y_i (Fig. 16) was expected; i.e. the more pounds landed the greater the number of shrimp tails in the landings, and vice versa. However, biological year mean count, N_i/Y_i (Fig. 17A) was not constant, because simulated distributions of w and Y_i were not constant over biological years (Fig. 12A–C, Fig. 13). Biological year mean tail weight (Y_i/N_i) also was not constant (Fig. 17B). We emphasize that N_i/Y_i and Y_i/N_i are crude estimates of mean count and mean tail weight, respectively, and do not represent biological year central tendency of C and w in the landings very well. Trends in N_i/Y_i (Fig. 17A) and Y_i/N_i (Fig. 17B) were cubic (sigmoid), mirroring each other as expected.

Tail Weight at Which Half of the Biological Year Yield was Harvested

The cubic trend in $w50_i$ is shown in Figure 18. As expected, it is similar in shape to that of Y_i/N_i (Fig. 17B). However, the two trends (Fig. 17B, Fig. 18) were not parallel, because the slope of the regression of $w50_i$ on Y_i/N_i did not equal 1 (Fig. 19). Instead, $w50_i$ was 1.459 times Y_i/N_i. Although significantly different from zero, the intercept of the regression of $w50_i$ on Y_i/N_i was very small (i.e. near the origin).

Discussion

It is clear that brown shrimp landings data should be filtered, edited, and residual records representing outlier count categories removed before distributions of shrimp tail weight are simulated. The same should be (and in most cases have been) done before numbers of shrimp are estimated from landings within count categories, regardless of the algorithm used to estimate numbers of shrimp within count categories, unless the algorithms are based on actual sampling of size distributions within count categories (Ehrhardt and Legault, 1996). The problem of unreported landings and other limitations of reported landings data affect not only our simulations, but all other uses of reported landings to estimate numbers of shrimp within count categories. These data problems cannot be rectified retroactively, but should be addressed in the future.

Our simulated biological year distributions of brown shrimp tail weight could be biased to unknown degrees by many factors. This is true of all estimates of numbers of shrimp derived from landings within count categories, whether at the highest possible level of data resolution (i.e. an individual shrimping trip within a statistical subarea, depth zone, and month), or at lower levels of data resolution represented by various spatial-temporal aggregations of landings data, including ours. Our simulated distributions of shrimp tail weight should not be taken as equivalent to distributions of brown shrimp tail weight in the population of the northern Gulf of Mexico. However, our simulated distributions of w in biological year landings no doubt have some yet undetermined relationship to actual distributions of shrimp tail weight in the brown shrimp population in biological years. This relationship cannot be determined retroactively due to lack of or paucity of required data. Unreported landings are much less than reported landings, but our simulated distributions of shrimp tail weight only represent landings that were reported and archived.

Despite landings data deficiencies, our simulated distributions of w, and other fishery-dependent statistics derived from them, can be useful in examining changes in the brown shrimp fishery over biological years. Their relationships to other important fishery-dependent and fishery-independent variables could be examined in attempts to explain causes and effects.

Our method could be applicable to fisheries of other penaeid shrimp species for which landings are recorded within size categories expressed in C or w. It might also be applicable to finfish fisheries in which landings are reported within size categories expressed in number of fish per unit weight or in weight per fish. The method may also be applicable to shrimp landings aggregated at spatial-temporal levels lower (i.e. higher resolution) than that of an entire fishery and biological year.

Our results suggest that brown shrimp were fully recruited to the fishery at small sizes in each biological year, then declined in number with w in a pattern similar but not identical to that of a negative exponential curve. In a study of distributions of growth rates of shrimp in captivity, Banks et al. (2009) examined effects of bin width, sample size, and sampling frequency on distributions

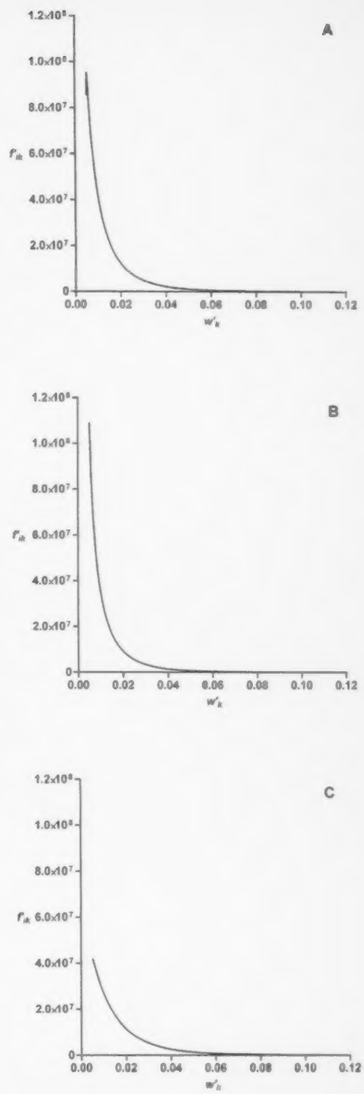

Figure 12.—Simulated distributions of w (i.e. the relationship between f'_{ik} and w'_k) for brown shrimp in biological years (A) 1986, (B) 1996, and (C) 2006.

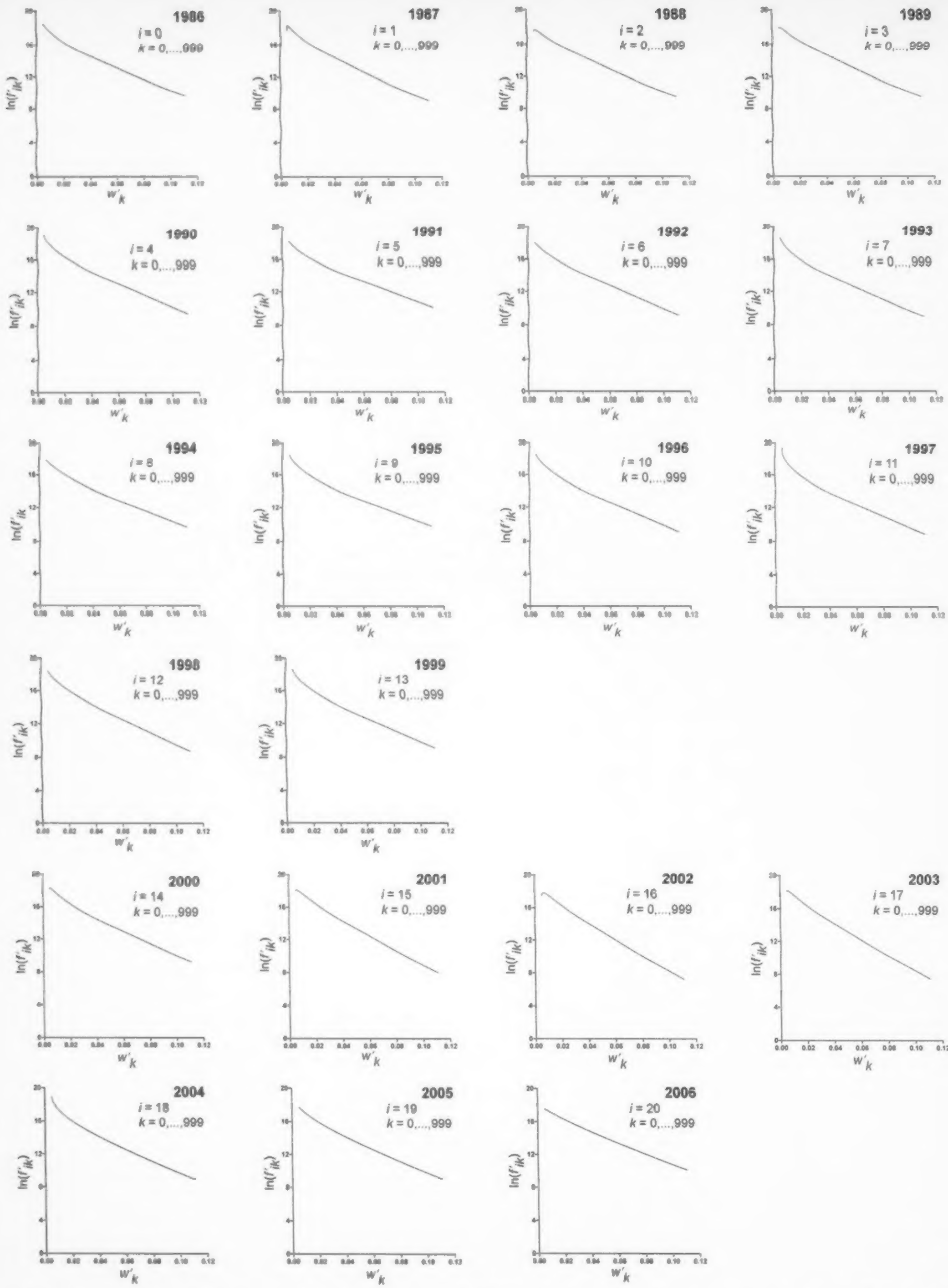

Figure 13.—Simulated distributions of w for brown shrimp in biological years 1986–2006, as shown with the ordinate in natural logarithmic scale (i.e. the relationship between $\ln(f'_{ik})$ and w'_k).

of weight per shrimp. Interestingly, the shapes of their distributions of weight per shrimp were similar to those of our simulated distributions of w. Although we did not simulate relative distributions of w or corresponding cumulative relative distributions of w, we noted that they could be simulated from our approach, and they too might be of interest and use in shrimp stock assessments.

Simulated biological year distributions of w could be used to estimate numbers of parents and recruits, for purposes of determining parent-recruit relationships (Rothschild and Brunenmeister, 1984; Gracia, 1991; Ehrhardt and Legault, 1996; Parrack[1]; Nichols[2]). Numbers of parents or recruits could be extracted from curves representing distributions of w by integrating them over the size ranges of parents and recruits. However, estimates or assumptions about size at maturity and growth patterns of males and females would be required, as well as estimates of size-specific sex ratios in the landings (Gracia, 1991; Ehrhardt and Legault, 1996 Parrack[1], Nichols[2]).

It may be possible to estimate instantaneous total mortality rate (Z) from simulated biological year distributions of w by transforming them to bounded length distributions and applying length-based models similar to those of Ehrhardt and Ault (1992) (Ehrhardt[6]).

[6]Ehrhardt, N. M. Rosentiel School of Marine and Atmospheric Science, Miami, FL. Personal commun., August 2010.

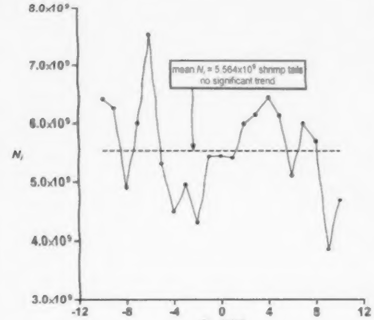

Figure 14.—Simulated biological year total number of brown shrimp tails, N_i, vs. coded biological year (T_i – 1996).

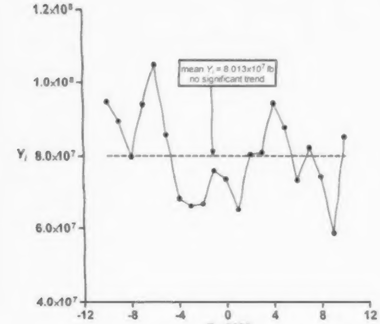

Figure 15.—Brown shrimp yield, Y_i, vs. coded biological year (T_i–1996).

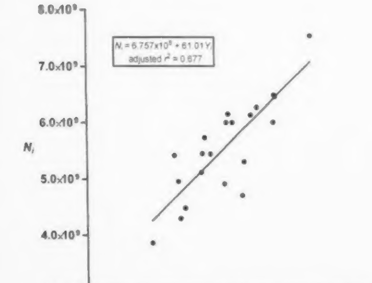

Figure 16.—Linear relationship between simulated total number of brown shrimp tails, N_i, and yield, Y_i.

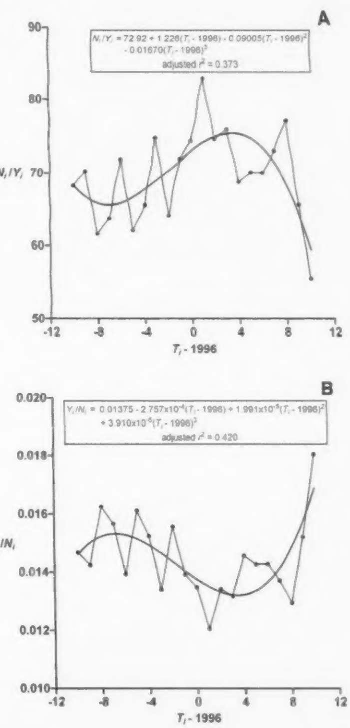

Figure 17.—Cubic trends in (A) biological year mean count, N_i/Y_i, vs. coded biological year (T_i–1996), and in (B) biological year mean pounds per shrimp tail, Y_i/N_i, vs. coded biological year (T_i – 1996).

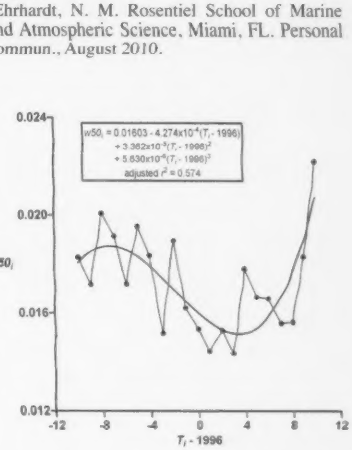

Figure 18.—Cubic trend in $w50_i$, the simulated pounds per shrimp tail at which half of the brown shrimp biological year yield, Y_i, was harvested, vs. coded biological year (T_i – 1996).

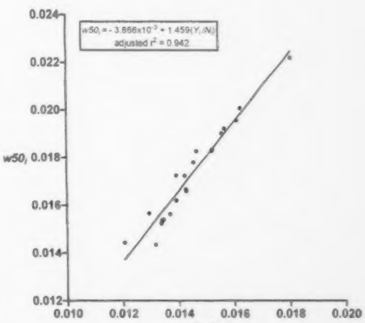

Figure 19.—Linear relationship between $w50_i$, the simulated pounds per shrimp tail at which half of the brown shrimp biological year yield, Y_i, was harvested, and biological year mean pounds per shrimp tail, Y_i/N_i.

Alternatively, the length-based models used by Ehrhardt and Ault (1992) might be reformulated for direct application to biological year distributions of w for purposes of estimating Z (Ehrhardt[6]). Biological year distributions of w could also be transformed to age-frequencies for age-structured stock assessments. This would require conversion of tail weight to age using sex-specific growth curves and knowledge of size-specific sex ratios in the landings (Parrack, 1979; Rothschild and Brunenmeister, 1984; Gracia, 1991; Ehrhardt and Legault, 1996; Parrack[1]; Nichols[2]).

Simulated distributions of w of brown shrimp in biological year reported landings are linked, by definition and calculations, to biological year yield. Fishing effort influences size-composition of the landings and therefore influences yield, although environmental variables affecting recruitment also affect yield (Caillouet et al., 2008; Nance et al., 2010). Numbers of shrimp estimated from landings within count categories have been used in evaluating the influence of environmental factors on abundance, growth, and survival (Diop et al., 2007).

Our method provides an alternate way to estimate abundance of shrimp in reported annual landings, as compared to algorithms used by previous investigators. However, the relationship between abundance of shrimp in the landings and in the population remains undetermined. Our simulated distributions of w provide examples for comparison with explicit or implicit assumptions made by previous investigators about the distributions of C and w. They also provide information of potential use in developing new estimators of number of shrimp from landings data, based on statistical estimation theory and the underlying distribution of w or C. Finally, there may be other useful applications of our approach and results that we have not realized or anticipated.

Acknowledgments

Special recognition goes to Charles H. Lyles, Jr., for his pioneering development of the system used to collect and report shrimp fishery statistics, and to all shrimp industry participants whose cooperation made it possible over the years. We are especially grateful to those who perpetuated and improved this system, and to those who collected, processed, and archived shrimp fishery statistics, making them available for analyses such as ours. Joseph H. Kutkuhn's comprehensive statistical examination and evaluation provided an early and important understanding of the usefulness and limitations of landings data in shrimp stock assessment. Succeeding investigators expanded and improved this understanding, for which we are grateful. We greatly appreciated reviews of our manuscript by Nelson M. Ehrhardt, and three anonymous reviewers. We thank Jo Anne Williams for assistance in drafting the figures; James Primrose and John Cole for assistance in landings data compilation; and Brian Linton, James A. Bailey, and Stephen A. Bailey for assistance with derivatives of the modified Richards function, and in solving this function for $w50$. This paper is dedicated to the memory of the senior author's parents, Charles W. Caillouet, Sr. (1908–1971) and Elida P. Millet Caillouet (1906–2004).

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Classification of Coastal Communities Reporting Commercial Fish Landings in the U.S. Northeast Region: Developing and Testing a Methodology

SARAH L. SMITH, RICHARD B. POLLNAC, LISA L. COLBURN, and JULIA OLSON

Introduction

This paper introduces a method for classifying coastal communities for either sampling purposes or further analysis. Along the coastline from North Carolina to the Canadian border we find nearly 2,000 communities associated with commercial and/or recreational fishing. When NOAA's National Marine Fisheries Service (NMFS) plans to implement fishery management plans, it is necessary to conduct (among other analyses) a social impact assessment (SIA). These SIA's can be quite complex and time consuming (e.g. Pollnac et al., 2006); nevertheless, they are often required to be submitted in a very short time period. In an attempt to be prepared to conduct SIA on short notice, all NMFS Regions have prepared profiles of a subset of the numerous coastal communities with fishing activity. These are called Community Profiles. This raises the question of how one selects the communities to be profiled.

One hundred seventy-seven community profiles were created and have been posted on the web site "Community Profiles for the Northeast U.S. Fisheries" (http://www.nefsc.noaa.gov/read/socialsci/community_profiles/). The profiles were developed as part of a nationwide initiative to develop community profiles for each of the NMFS regions for use in Environmental Impact Statements (EIS). The profiles provide basic descriptive information, including a historic, demographic, cultural, and economic context, for understanding a community's involvement in fishing and also furnishes a baseline from which to measure future change.

Thus far, communities to be profiled have been selected on the basis of size and importance of fishery, types of fishing present, and overall knowledge possessed by experts working in the region. We posit that this technique is too unsystematic for this important endeavor, as important fishing communities could possibly be overlooked. SIA's describe important implications of potential impacts of management actions on fishermen and the communities in which they live. If SIA's are based on the limited information available in community profiles, and if the communities profiled are not representative of the communities involved in the target fishery, then the SIA's produced may not reflect an understanding of the potential impact of fishery management plans (FMP's). Inaccurate SIA's can result in decreased fishing activity, which may affect household and community well-being and lead to social dysfunction within communities reliant on fishing, exacerbating the resistance to fisheries management that is evident in the Northeast Region and elsewhere (Pollnac et al., 2006).

If we could classify the large number of coastal communities into smaller, meaningful groupings, SIA data from a sample of communities within relevant subgroups would provide more accurate data for management decision making. Relevant subgroups would be those characterized by varying degrees of nonfishery and fishery attributes associated with participation in the target fishery or fisheries. Hence, the subgroups should be based on multivariate criteria—an analytic task for some form of numerical taxonomy.

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ABSTRACT—The National Marine Fisheries Service is required by law to conduct social impact assessments of communities impacted by fishery management plans. To facilitate this process, we developed a technique for grouping communities based on common sociocultural attributes. Multivariate data reduction techniques (e.g. principal component analyses, cluster analyses) were used to classify Northeast U.S. fishing communities based on census and fisheries data. The comparisons indicate that the clusters represent real groupings that can be verified with the profiles. We then selected communities representative of different values on these multivariate dimensions for in-depth analysis. The derived clusters are then compared based on more detailed data from fishing community profiles. Ground-truthing (e.g. visiting the communities and collecting primary information) a sample of communities from three clusters (two overlapping geographically) indicates that the more remote techniques are sufficient for typing the communities for further in-depth analyses. The in-depth analyses provide additional important information which we contend is representative of all communities within the cluster.

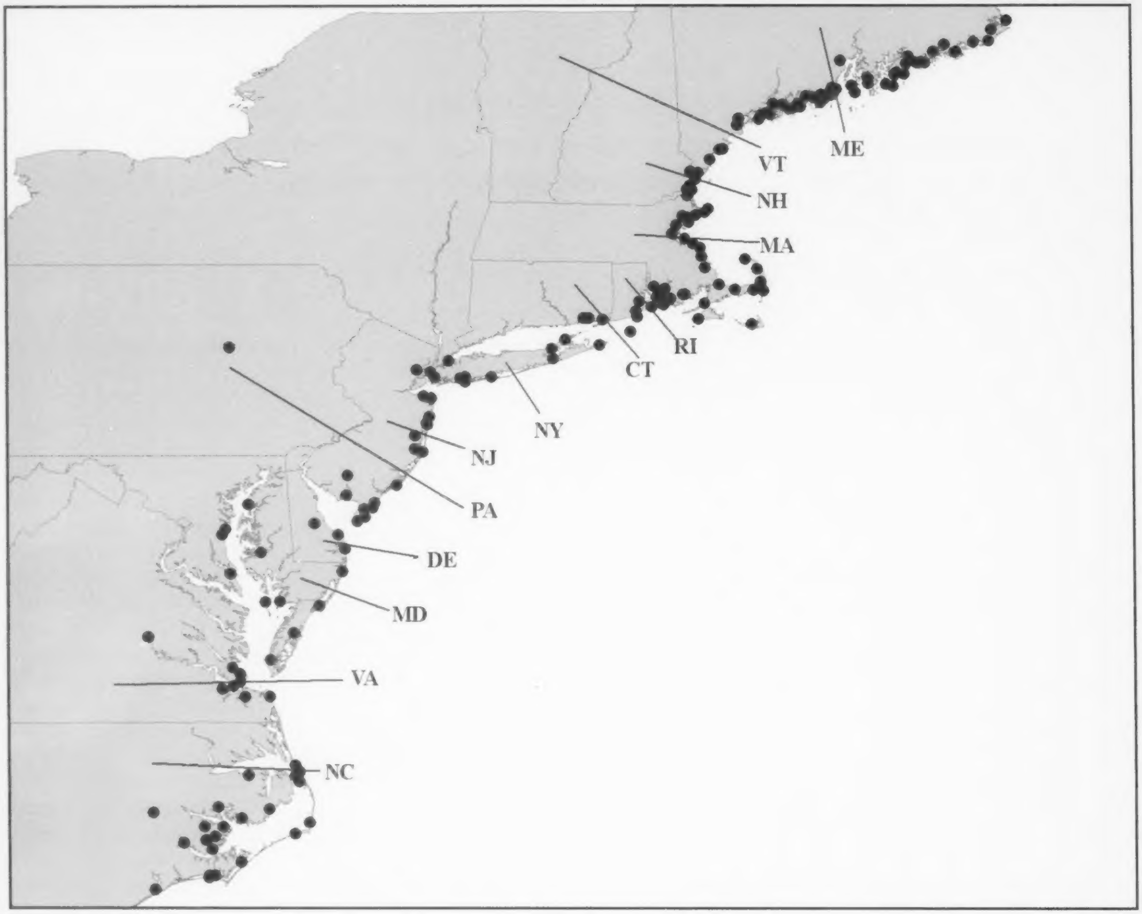

Figure 1.—Communities profiled for the U.S. northeast community profiling project.

Many disciplines use multivariate analyses for the purposes of classification. For example, modern biology uses numerical-based systematics to classify organisms—tools such as multiple discriminant analysis and cluster analysis. These techniques are not foolproof. First, unless all attributes of the "thing" to be classified are used, human decision making is significantly involved in the process. Second, a variety of techniques are used in numerical taxonomy (Sokal and Sneath, 1963), and the method selected can influence the results (Frey and Duek, 2007; Brusco and Kohn, 2008). For this reason, we felt it essential to test our results against several independent data sets, a process we refer to as "ground-truthing."

Methods

Sample

The attributes selected for the numerical taxonomy are derived from the NMFS "Social Science Data Base" (NMFS-SSDB) which includes commercial fisheries and U.S. Census data for 1,835 "ports" from North Carolina to the Canadian border. Those ports selected for community profiling are depicted in Figure 1 to demonstrate the geographic range of communities. By "ports" we mean coastal communities that report commercial fish landings, are the vessel owner port of residence, or homeport for permitted vessels, or are sites of processing, seafood/shellfish dealers, or recreational fishing activity. From the NMFS-SSDB, we selected 43 "fishery" and 25 "social" variables for analysis—a total of 68 variables (Tables 1, 2). The fishery variables selected were drawn from a number of variables characterizing fishing activity over a ten-year period, and included data relevant to quantifying fishing activity, such as landings by species, numbers of vessels, and numbers of vessel owners. The social variables used were those data from the 2000 United States Census that

could most accurately reflect changes in port communities that may result from or result in changes in fishing activity, such as the numbers of people employed in fishing related activities, the number of people who are self-employed, median household and per capita income, and other relevant factors.

Data Reduction Techniques

Principal component analysis was selected as the most appropriate technique for accomplishing a reduction in variables because it creates a smaller number of new variables, grouping them into factors based on shared covariance. The 43 fishery and 25 social variables were reduced to fewer variables with the use of principal component analyses. The scree test (Cattell, 1966) was used to determine the number of components, resulting in four components which account for a total of 70.4 percent of the variance in the data set. Components were rotated using the varimax technique. The results of this analysis are found in Table 1. Items loading highest on the first component (large landings, large vessels, sea scallops, *Placopecten magellanicus;* large groundfish, skates, *Raja* spp.; red crab, *Geryon quinquedens*; and monkfish, *Lophius americanus*, decreasing landings) reflect a fishery characterized by large vessels and large, but decreasing, landings of sea scallops, large groundfish, skates, red crab, and monkfish. Items loading highest on the second component (small vessels, many vessels, lobster, *Homarus americanus*; herring, *Clupea harengus*; and many species) indicate a fishery characterized by many small vessels, landing various species including lobster and herring. The third component reflects a fishery characterized by medium-sized vessels with landings composed principally of bluefish, *Pomatomus saltatrix;* tilefish, *Lopholatilus chamaeleonticeps;* butterfish, *Peprilus triacanthus;* mackerel, *Scomber scombrus;* squid, *Loligo pealeii, Illex illecebrosus;* summer flounder, *Paralichthys dentatus;* scup, *Stenotomus chrysops;* and black sea bass, *Centropristis striata*. The final component reflects ports with changing numbers and sizes of vessels.

Table 1.—Principal component analysis of fishery data. Items in boldface type indicate highest loadings on those factors.

	Component			
Variable	1	2	3	4
Value of scallops, 2003	**0.932**	0.024	0.068	0.201
Landings value for home-ported vessels, 2004	**0.930**	0.196	0.215	0.110
Number of large vessels (>70ft), 2004	**0.932**	0.184	0.219	0.084
Average value of home-ported vessels, 1997–2003	**0.907**	0.243	0.265	0.059
Value of landings at dealer reported port, 2004	**0.867**	0.282	0.187	0.140
Number of large vessels by owner city, 2003	**0.881**	0.220	0.122	0.182
Total gross tonnage for home-ported vessels	**0.852**	0.345	0.326	0.154
Value of large-mesh groundfish, 2003	**0.832**	0.407	0.007	0.023
Value of skates, 2003	**0.821**	0.175	0.220	0.071
Average landed value, 1997–2003	**0.816**	0.290	0.248	0.071
Total gross tonnage for city owner vessels, 2004	**0.789**	0.376	0.185	0.302
Value of red crab, 2003	**0.730**	0.014	–0.042	0.132
Value of monkfish, 2003	**0.668**	0.435	0.216	–0.058
Number of small vessels (<50ft) by owner city, 2003	–0.027	**0.901**	0.054	0.307
Number of small vessels by homeport, 2003	0.041	**0.904**	0.272	0.162
Average number of vessels by owner city, 1997–2003	0.322	**0.843**	0.128	0.282
Number of vessels by owner city, 2004	0.350	**0.825**	0.105	0.346
Average number of home-ported vessels, 1997–2003	0.393	**0.798**	0.381	0.097
Number of home-ported vessels, 2004	0.416	**0.793**	0.344	0.169
Number of active owner city vessels, 2004	0.507	**0.691**	0.193	0.308
Number of federal dealers, 2004	0.487	**0.657**	0.071	0.020
Number of active home-ported vessels, 2004	0.535	**0.646**	0.451	0.145
Average number of dealers, 1997–2003	0.484	**0.688**	0.084	–0.020
Value of lobster, 2003	0.087	**0.575**	0.012	0.091
Value of herring, 2003	0.516	**0.555**	–0.023	–0.106
Number of medium vessels (50–70ft) by owner city, 2003	0.502	**0.525**	0.281	0.282
Species diversity (number of species landed), 2003	0.147	**0.502**	0.452	–0.026
Value of summer flounder, scup, black sea bass, 2003	0.243	0.087	**0.780**	0.002
Value of butterfish, mackerel, squid, 2003	0.193	0.103	**0.710**	–0.080
Value of smallmesh multispecies, 2003	0.440	0.119	**0.683**	0.201
Value of tilefish, 2003	–0.093	0.070	**0.648**	0.431
Number of medium (50–70ft) vessels by home-port 03	0.518	0.489	**0.557**	–0.003
Value of bluefish, 2003	–0.007	0.107	**0.488**	0.147
Difference in HP gross tons from 1997/98 to 2003/04	–0.230	0.021	–0.199	**–0.776**
Difference in city owner gross tons from 1997/98 to 2003/04	–0.306	–0.094	–0.339	**–0.656**
Difference in HP vessels from 1997/98 to 2003/04	–0.130	–0.304	0.097	**–0.641**
Difference in number of city owner vessels from 1997/98 to 2003/04	–0.200	–0.274	0.019	**–0.622**
Value of dogfish, 2003	–0.059	0.398	0.055	0.028
Value of surf clam, ocean quahog, 2003	0.357	0.013	0.116	–0.006
Difference in dealers from 1997/98 to 2003/04	0.144	0.363	0.024	–0.156
Value of other species, 2003	0.091	0.065	0.166	–0.025
Difference in landings values for 1997/98 to 2003/04	**–0.857**	–0.247	–0.052	–0.227
Difference in sum landings for HP vessels 1997/98 to 2003/04	**–0.928**	–0.101	–0.085	–0.242
Percent total variance	**32.5**	**21.1**	**9.7**	**7.1**

Table 2 presents a principal component analysis of a set of variables from the 2000 Census. Variables selected can be seen in Table 2. Once again, the scree test was used to select number of components and components were rotated using the varimax technique. This resulted in three components which explain a total of 52.9 percent of the total variance in the data set.

Component scores representing the position of each port on each component were created for each port. The component scores are the sum of the component coefficients times the sample standardized variables. These coefficients are proportional to the component loadings. Hence, items with high positive loadings contribute more strongly to a positive component score than those with low or negative loadings. Nevertheless, all items contribute (or subtract) from the score; hence, items with moderately high loadings on more than one component (e.g. percent black and percent white in Table 2) will contribute at a moderate level, although differently, to the component scores associated with each of the components. This type of component score provides the best representation of the data.

Cluster Analysis

Cluster analysis was then used to systematically group like communities based on these newly-created compo-

nent scores. As a means of combining the communities into relevant subgroups to be used for efficiently obtaining data for management decision making, we used K-means cluster analysis (Hartigan and Wong, 1979). The K-means procedure split the fishing communities into a selected number of groups by simultaneously maximizing between group (or cluster) variation and minimizing within group variation. Component scores, which were used as input to the cluster analysis, are standardized, hence providing equal weight for each of the nine components used. Only cases that had no missing data on any of the variables used in the principal component analyses are used in the cluster analysis (n=446). This eliminated any ports that did not have associated census data, which occurred when the port name did not correspond to either a geopolitically defined entity or a census designated place, bringing the number of ports used in the analysis from 1,835 down to 446. The procedure first selects the same number of "seeds" as the number of groups desired. The "seeds" selected are as far as possible from the center of all the cases. Then all cases are assigned to the nearest "seed," and cases are reassigned to other clusters, as needed, to reduce within-groups sum of squares.

Table 2.—Principal component analysis of Census data. Items in boldface type indicate highest loadings on those factors

	Component		
Variable	1	2	3
Median household income	**–0.793**	0.395	0.018
High school (%)	**–0.766**	0.172	–0.413
High school males (%)	**–0.745**	0.243	–0.359
Poverty rate	**0.735**	–0.209	0.309
High school female (%)	**–0.732**	0.088	–0.444
Unemployed (%)	**0.727**	0.279	0.038
Unemployed males (%)	**0.659**	0.277	0.029
Unemployed females (%)	**0.657**	0.229	0.044
Household income >200K (%)	**–0.624**	0.302	0.104
Share of HH income >200k	**–0.579**	0.296	0.118
Share of HH income retired	**0.526**	–0.291	–0.247
Black (%)	**0.520**	0.121	**0.447**
Males in fishing related job (%)	0.080	**–0.846**	0.002
Fishing related employment (%)	0.054	**–0.845**	0.018
Population in urban area (%)	–0.156	**0.599**	0.271
Females in fishing related job (%)	0.035	**–0.549**	0.001
Tourist housing (%)	0.016	**–0.475**	–0.256
Hispanic (%)	0.216	0.174	**0.766**
Other ethnic group (%)	0.276	0.135	**0.745**
White (%)	**–0.455**	–0.200	**–0.690**
Two or more ethnicities	0.187	0.155	**0.612**
Population	–0.078	–0.095	**0.570**
Aggregate household income	–0.111	–0.091	**0.566**
Asian (%)	–0.230	0.280	**0.451**
Male population (%)	–0.179	–0.186	0.083
Percent of Total Variance	**24.072**	**13.358**	**15.469**

Number of clusters selected was based on an iterative procedure wherein we started at a relatively low number, examined the output, then increased the number if it was felt that, based on our knowledge of the ports, similar ports were combined. This iterative procedure resulted in a decision to use 40 clusters as the requested number. The results of the analysis are in Appendix I, and an example of selected clusters is provided in Table 3.

The F-ratios across the 40 groups are impressive, but one must remember that they are an artifact of the clustering technique which maximizes these values. Twelve of the clusters contain only one port, as illustrated by Montauk, N.Y., in Table 3. We believe that this is a valid clustering since our knowledge of ports included in these single port clusters suggests that they are unique, and any grouping of them with other ports would be questionable. Each of these single-port clusters represents a community with either an exceptionally large fishery (e.g. New Bedford, Mass.; Cape May, N.J.), or is a large city and thus the census data factors are very different from the other clusters (e.g. New York, N.Y.; Boston, Mass.). That these ports appear in their own individual clusters indicate that they are unique enough to be studied on their own and should not be grouped with other ports.

Note the distance for Montauk. This is a measure of the distance of a port from the center of all the cases in the cluster, and since there is only one, the distance is zero. In cluster 8, Portsmouth, N.H., is closest to the center of all eight cases in the cluster for all seven component scores. Hence, this distance measure can be used in selecting cases from clusters for more intensive analysis.

For example, one may only desire ports close to the center or want a representative sample from the cluster and select ports across the range of distances. Numbers of ports in each cluster range from 1 to 123. As can be seen in Appendix I, many of the clusters (12) contain only a single case, followed by 7 clusters containing 2–9 cases, 2 clusters containing 22 cases, 3 clusters containing 32–38 cases, and 1 cluster containing 57 cases (not all clusters are shown in Appendix I).

Those clusters plotted in multidimensional space allow us to view similarities and differences on more than one component at a time. Figure 2 illustrates relative positioning of the 12 single-port clusters on one social component (population, percent in fishing related jobs and tourist housing) and two fishery components (component 2: small vessels, landing many species including lobster and herring and component 4: ports with decreasing numbers and sizes of vessels). A high number on fishery component 4 reflects rising numbers and sizes of vessels; hence, the name for the dimension—Rising.

Figure 3 illustrates relative positioning of seven multiport clusters in the same three-dimensional space. In this figure, the number following the name indicates cluster number as indicated in Appendix I. Where there are only a few states involved (MAME32), the states are abbreviated (e.g. MAME32 is cluster 32 which includes six cases from Maine and Massachusetts). MIXED refers to too many states to abbreviate in a brief

title. GROUNDT refers to clusters that are "ground-truthed" (see below). You can see the ports included in cluster 8 in Table 3. Ports included in cluster 40 are mainly in Massachusetts with some from Maine, New Hampshire, and Rhode Island.

Plots of clusters, such as those illustrated in Figures 2 and 3, can be rotated to identify groups of communities that cluster in various selected component spaces, such as clusters numbered 8, 32, and 40. Clusters can then be examined by mean scores on all components, as in Figure 4. While communities in these three clusters overlap geographically and are quite similar on most of the fishery and social components, clusters 8 and 40 are on opposite sides of the component mean (zero for a standardized variable) with regard to growth trends. The type of analysis presented here allows one to identify differences between any subset of clusters in the data set, but to illustrate the process we will focus on these two clusters (8 and 40) which are used in further analyses below.

Testing the Usefulness of the Cluster Analysis

If the cluster analysis actually does group communities which differ on sociocultural and fishery variables, we would expect these differences to be manifest in other aspects of the community which were not measured as part of the original data set. To test this hypothesis we coded a select set of sociocultural variables found in the existing 177 community profiles, which were compiled from a wide range of available data. Eleven variables not used in the cluster analysis were coded, and percent distribution across clusters 8 and 40 can be found in Figure 5. Despite the fact that there are some large differences between clusters 8 and 40, for example, presence of a fishermen's memorial (50% versus 11%, respectively; Fisher's Exact Test $p>0.05$) the small number of communities in each cluster (8 and 9, respectively) necessitates a relatively large difference to achieve statistical significance.

It would be more revealing to examine combinations of the sociocultural variables than individual items. Once again, we used principal component analysis with varimax rotation to develop scales from the profile-derived, sociocultural data set. Number of components was selected on the basis of the scree test. The results of the analysis are in Table 4.

Table 4 indicates that the two components account for 43% of the variance in the data set. Items loading highest on the first component are related to aspects of a commercial fishing culture, such as presence of a commercial fishermen's memorial, a fishermen's museum, blessing of the commercial fleet, etc. Items loading highest on the

Table 3.—Segment of K–Means cluster analysis output.

Summary statistics for all cases

Variable	Between SS	df	Within SS	df	F–ratio
FAC1FSH9 (fishery component 1)	1796.537	39	21.907	406	853.716
FAC2FSH9 (fishery component 2)	1421.244	39	69.732	406	212.176
FAC3FSH9 (fishery component 3)	1074.305	39	36.679	406	304.911
FAC4FSH9 (fishery component 4)	1491.341	39	100.399	406	154.635
SOCFA1 (social component 1)	281.368	39	119.428	406	24.526
SOCFA2 (social component 2)	760.698	39	88.195	406	89.790
SOCFA3 (social component 3)	435.648	39	86.124	406	52.659
TOTAL	7261.142	273	522.465	2842	

Cluster 7 of 40 contains 1 cases

Members			Statistics			
Case	Distance	Variable	Minimum	Mean	Maximum	St.Dev.
NY, Montauk	0.00	FAC1FSH9	–4.46	–4.46	–4.46	–
		FAC2FSH9	2.60	2.60	2.60	–
		FAC3FSH9	22.73	22.73	22.73	–
		FAC4FSH9	18.56	18.56	18.56	–
		SOCFA1	0.91	0.91	0.91	–
		SOCFA2	–0.94	–0.94	–0.94	–
		SOCFA3	0.37	0.37	0.37	–

Cluster 8 of 40 contains 8 cases

Members			Statistics			
Case	Distance	Variable	Minimum	Mean	Maximum	St.Dev.
MA, Harwich	0.51	FAC1FSH9	–1.25	–0.64	0.62	0.61
MA, Rockport	0.34	FAC2FSH9	3.03	4.08	5.46	0.85
MA, Plymouth	0.52	FAC3FSH9	–0.90	–0.14	0.82	0.57
MA, Scituate	0.88	FAC4FSH9	–0.47	0.96	1.85	0.74
ME, Kittery	0.43	SOCFA1	–0.90	–0.28	0.38	0.40
NH, Hampton	0.47	SOCFA2	–0.30	0.07	0.31	0.22
NH, Portsmouth	0.29	SOCFA3	–0.92	–0.47	–0.20	0.24
RI, Narragansett	0.58					

Cluster 9 of 40 contains 3 cases

Members			Statistics			
Case	Distance	Variable	Minimum	Mean	Maximum	St.Dev.
ME, Stonington	0.33	FAC1FSH9	–0.85	–0.77	–0.65	0.10
ME, Vinalhaven	0.47	FAC2FSH9	5.41	6.29	6.76	0.76
ME, Jonesport	0.47	FAC3FSH9	–2.82	–2.47	–1.78	0.59
		FAC4FSH9	2.49	2.98	3.46	0.48
		SOCFA1	–0.33	0.33	0.73	0.57
		SOCFA2	–4.95	–4.25	–3.89	0.61
		SOCFA3	–0.10	0.13	0.36	0.23

Table 4.—Principal component analysis of cultural and recreational fishing information from profiles

Item	Fishing Culture	Fishing Recreation
Fishermen's festival	0.667	0.258
Blessing of fleet	0.657	–0.001
Fishermen's memorial	0.619	–0.257
Fishermen's assistance	0.597	–0.314
Fishermen's competition	0.553	0.107
Fishermen's association	0.539	0.081
Recreational fishing pier	–0.090	0.718
Fishing tournament	–0.010	0.713
Fishing education	0.361	0.487
Percent variance	26.109	16.777

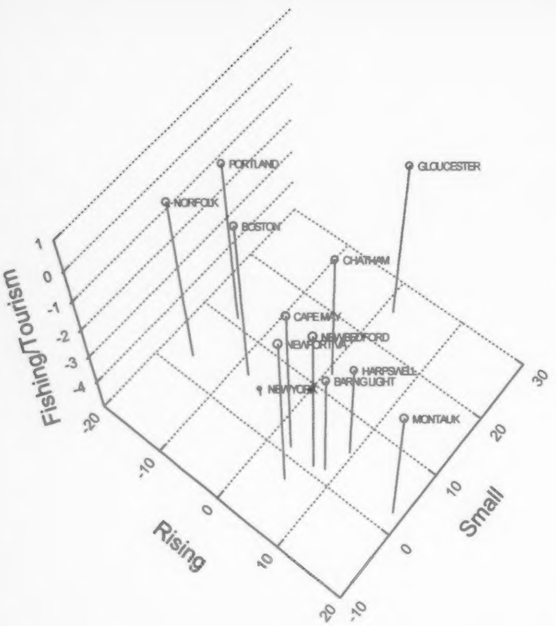

Figure 2.—Plot of single port clusters on one social and two fishery components.

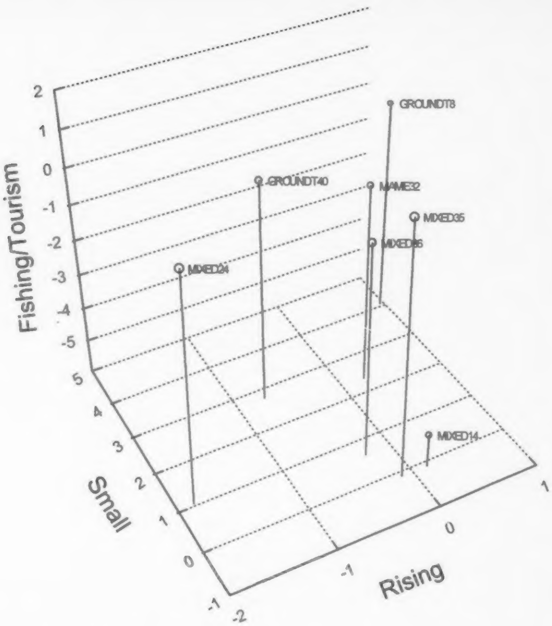

Figure 3.—Plot of multiple port clusters on one social and two fishery components.

second component are more related to recreational fishing, including presence of a recreational fishing tournament and a recreational fishing pier. Presence of fishermen's educational programs loads about the same on both components. Component scores, as described above, were calculated for each port in the profile data set.

Since sample size within clusters 8 and 40 are relatively small for statistical analyses, we decided to cluster the clusters to allow comparison between larger groupings of ports that include both clusters 8 and 40. Data input were mean values for each of the 40 clusters (Appendix I) on the four fishery and three social component scores described above, and a hierarchical cluster analysis using median linkage and Euclidean distances was performed (Appendix II). A segment of the hierarchical tree which will be analyzed further is in Figure 6. All of the clusters found in Figure 6 can be found within cluster 1 of a K-means cluster analysis of the same data set (Appendix III).

We will now compare two clusters depicted in Figure 6 on the two scales developed from the profile data. We will refer to the four clusters represented by MASS/ME32 through MIXED38 depicted at the bottom part of Figure 6 as Group A (n=25), and MIXED1 through MIXED12 as Group B (n=31). Mean scores for Group A and Group B on the Fishing Culture Component are 0.297 and –0.594, respectively ($t = 4.393$, df $= 54$, $p<0.001$), and on the Recreational Component they are –0.247 and 0.192, respectively ($t = 1.581$, df $= 54$, $p>0.05$). This analysis indicates that the cluster analysis identified clusters that differ on sociocultural variables not included in the initial data set used for the clustering, providing a measure of external validity for the analysis.

A final test of the usefulness of the clusters derived from the K-means cluster analysis was to "ground-truth" the various clusters. In contrast to the preceding analyses, which are based on secondary data (the initial database) and more detailed community profiles, which were also based on secondary data from publications, websites, and telephone inquiries as needed (see the community profiles), the ground-truthing is based on actual visits to the communities and interviews with community members.

The ground-truthing method used the following techniques:

1) A photo-survey that included infrastructure (dock areas, fish processing and marketing facilities), fishing related cultural items (fishermen's memorials, statues), and general snapshots that would provide an overall picture of the ambience of the community;
2) Interviews with key informants concerning infrastructure and other points included in the profiles to provide field validity checks;
3) A brief survey that included the following six questions: 1) If you were to list five things that characterize [community name],

what would they be? 2) Would you say that [community name] is a fishing community (if not included in the response to the first question)? 3) What are three important issues facing [community name] today? 4) Has [community name] changed over the past 5–10 years? How? 5) Would you advise a young person to live in [community name]? Why? 6) If the person interviewed is a fisherman, he or she will be asked "What's it like fishing out of [community name]?"

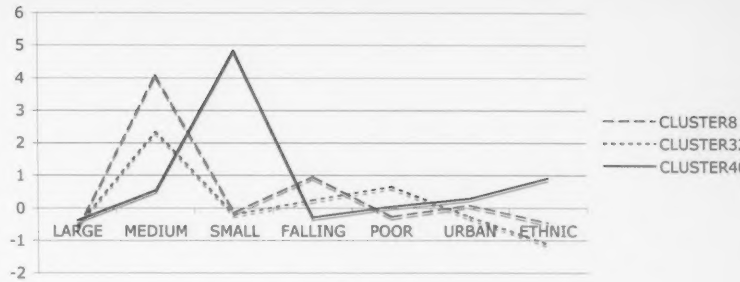

Figure 4.—Mean component values plotted for three similar clusters.

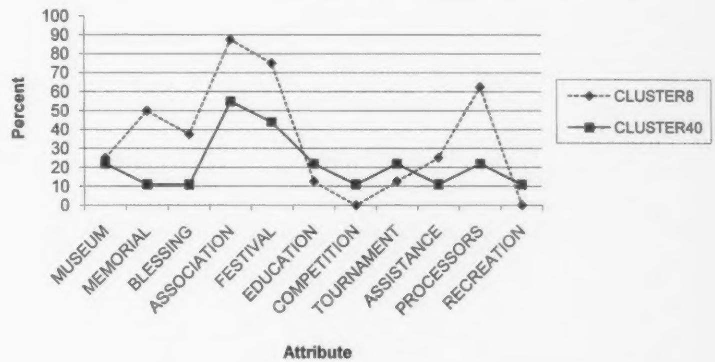

Figure 5.—Selected profile attributes compared across clusters 8 and 40.

To provide a rigorous test of the clustering technique we selected clusters 8 and 40 as the first two clusters to be compared. These two clusters overlap geographically and are composed of relatively small ports in Rhode Island, Massachusetts, and New Hampshire (Appendix I). Ground-truthed ports from Cluster 8 are Plymouth, Harwich, and Scituate, Mass., as well as Portsmouth, N.H. (Sample size of surveys (n=89). The ports from Cluster 40 that were ground-truthed are Seabrook, N.H., and Westport, Barnstable, and Marshfield, Mass. (n=81).

When ground-truthing was completed for the eight communities, we noted that communities from Cluster 8 were somehow "nicer." The people in the communities seemed to be friendlier, speaking of their community in a manner that made it seem more cohesive. These qualitative observations are supported by a content analysis of responses made by community members during the ground-truthing exercise. While 11% of those interviewed in Cluster 40 said their communities were "spread out" and "composed of different parts" only 2% of respondents from Cluster 8 made this observation ($\chi^2 = 5.505$, $p<0.05$).

Additionally, a common issue in coastal communities is that of "gentrification"—a change from being a fishing port to that of a desired residential and recreational location. This was manifested by respondents' complaints concerning the development of "condos," "million dollar homes," and an increase in "yuppies" as well as a "loss of character" in the port. Once again, Clusters 8 and 40 differed with respect to these responses. Forty-six percent of respondents from Cluster 8 voiced these complaints in contrast to only 20% from Cluster 40 ($\chi^2 = 13.175$, $p<0.001$). These findings provide more external validity to the results of the classification methods used.

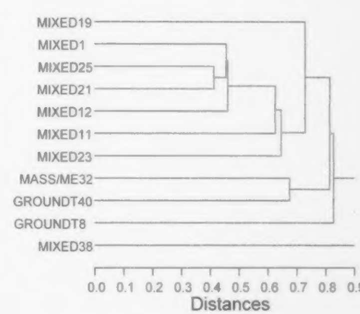

Figure 6.—Segment of hierarchial cluster analysis of 40 clusters from K-means cluster analysis

Conclusions

In sum, the tests of external validity for the cluster analyses provide support for the claim that the analysis actually did cluster communities into groupings that are different—different on the items used in the initial clustering as well as other variables identified by the analysis of the data from the community profiles and the ground-truthing exercise.

We argue here that this type of classification of coastal communities is a necessary first step in providing representative information to be used in SIA. Community Profiles form an important part of the information used in developing SIA's, and communities to be profiled have thus far been selected on the basis of size and importance of

fishery, types of fishing present, and overall knowledge possessed by experts working in the region. This technique is too unsystematic for such an important endeavor. SIA's detail important implications with regard to the impacts of management on fishermen and the communities in which they live. As noted in the introduction, the lack of a statistically representative range of communities that may be impacted by proposed regulations can result in inadequate SIA's, resulting in undesirable effects on household and community well-being. All of these can exacerbate the types of resistance to fisheries management that are evident in most, if not all, fisheries. Using the methodology described here to first select the communities to be profiled, as a way of improving the sampling process, would result in more representative and useful community profiles and, ultimately, improve SIA's.

The type of classification of coastal communities presented here should be done on a regular basis to reflect the rapid changes that are taking place in our fisheries. One of the principal components of the analysis of the fishery data reflected these changes. If regularly conducted, such analyses would allow those responsible for SIA's to observe the changes in fishing communities in terms of their similarities and differences, determine the factors influencing these changes, and use this information to craft more reliable and timely SIA's related to specific, proposed management measures.

Acknowledgments

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Appendix I.—K-Means Cluster Analysis.Distance metric is Euclidean distance, K-means splitting cases into 40 groups. Data for the following results were selected according to: HBOATS04> 0) AND (SOCMISDA= 0).

Summary statistics for all cases

Variable	Between SS	df	Within SS	df	F-ratio
FAC1FSH9	1796.537	39	21.907	406	853.716
FAC2FSH9	1421.244	39	69.732	406	212.176
FAC3FSH9	1074.305	39	36.679	406	304.911
FAC4FSH9	1491.341	39	100.399	406	154.635
SOCFA1	281.368	39	119.428	406	24.526
SOCFA2	760.698	39	88.195	406	89.790
SOCFA3	435.648	39	86.124	406	52.659
TOTAL	7261.142	273	522.4652	842	

Cluster 1 of 40 contains 57 cases

Members

Case	Distance
CT, Greenwich	0.58
CT, Guilford	0.21
CT, Madison	0.17
CT, North Branford	0.22
MA, Aquinnah	0.52
MA, West Tisbury	0.39
MA, Georgetown	0.20
MA, Manchester	0.41
MA, Middleton	0.26
MA, West Newbury	0.39
MA, Bedford	0.17
MA, Hopkinton	0.23
MA, Cohasset	0.39
MA, Dover	0.68
MA, Norfolk	0.33
MA, Norwood	0.26
MA, Marion	0.46
MA, Southborough	0.39
MA, Sutton	0.27
ME, Yarmouth	0.22
NC, Ocean Island Beach	0.46
NH, Hollis	0.25
NH, Greenland	0.21
NH, Hampton	0.33
NH, New Castle	0.38
NH, Windham	0.16
NJ, Medford	0.12
NJ, Avalon	0.37
NJ, East Brunswick	0.41
NJ, Sewaren	0.40
NJ, Manasquan	0.27
NJ, Monmouth	0.20
NJ, Rumson	0.56
NJ, Sea Bright	0.25
NJ, Wall	0.26
NJ, Wayne	0.24
NY, Atlantic Beach	0.11
NY, East Rockaway	0.23
NY, Lido Beach	0.20
NY, Massapequa	0.15
NY, Seaford	0.26
NY, Wantagh	0.20
NY, Babylon	0.20
NY, East Islip	0.25
NY, Huntington Bay	0.19
NY, Islip	0.44
NY, Mount Sinai	0.16
NY, Northport	0.17
NY, Oakdale	0.23
NY, Port Jefferson	0.20
NY, Sayville	0.16
NY, Southampton	0.43
NY, Stony Brook	0.10
NY, Armonk	0.60
NY, Bronxville	0.89
RI, Barrington	0.19
RI, East Greenwich	0.30

Statistics

Variable	Minimum	Mean	Maximum	St.Dev.
FAC1FSH9	−0.27	−0.06	0.09	0.07
FAC2FSH9	−0.31	−0.06	0.80	0.22
FAC3FSH9	−0.41	−0.10	0.62	0.14
FAC4FSH9	−0.45	0.15	1.31	0.31
SOCFA1	−2.98	−1.17	−0.40	0.57
SOCFA2	−0.75	0.38	1.44	0.38
SOCFA3	−0.67	0.00	1.05	0.42

continued

Appendix I.—(Continued).

Cluster 3 of 40 contains 1 case

Members		Statistics				
Case	Distance	Variable	Minimum	Mean	Maximum	St.Dev.
MA, New Bedford	0.00	FAC1FSH9	39.65	39.65	39.65	—
		FAC2FSH9	1.12	1.12	1.12	—
		FAC3FSH9	–0.68	–0.68	–0.68	—
		FAC4FSH9	6.91	6.91	6.91	—
		SOCFA1	1.94	1.94	1.94	—
		SOCFA2	0.10	0.10	0.10	—
		SOCFA3	1.50	1.50	1.50	—

Cluster 5 of 40 contains 1 case

Members		Statistics				
Case	Distance	Variable	Minimum	Mean	Maximum	St.Dev.
VA, Norfolk	0.00	FAC1FSH9	2.87	2.87	2.87	—
		FAC2FSH9	2.89	2.89	2.89	—
		FAC3FSH9	3.51	3.51	3.51	—
		FAC4FSH9	–15.71	–15.71	–15.71	—
		SOCFA1	1.12	1.12	1.12	—
		SOCFA2	0.41	0.41	0.41	—
		SOCFA3	1.10	1.10	1.10	—

Cluster 6 of 40 contains 1 case

Members		Statistics				
Case	Distance	Variable	Minimum	Mean	Maximum	St.Dev.
NJ, Barnegat Light	0.00	FAC1FSH9	1.27	1.27	1.27	—
		FAC2FSH9	1.67	1.67	1.67	—
		FAC3FSH9	6.20	6.20	6.20	—
		FAC4FSH9	8.33	8.33	8.33	—
		SOCFA1	–0.58	–0.58	–0.58	—
		SOCFA2	–1.31	–1.31	–1.31	—
		SOCFA3	–0.74	–0.74	–0.74	—

Cluster 7 of 40 contains 1 case

Members		Statistics				
Case	Distance	Variable	Minimum	Mean	Maximum	St.Dev.
NY, Montauk	0.00	FAC1FSH9	–4.46	–4.46	–4.46	—
		FAC2FSH9	2.60	2.60	2.60	—
		FAC3FSH9	22.73	22.73	22.73	—
		FAC4FSH9	18.56	18.56	18.56	—
		SOCFA1	0.91	0.91	0.91	—
		SOCFA2	–0.94	–0.94	–0.94	—
		SOCFA3	0.37	0.37	0.37	—

Cluster 8 of 40 contains 8 cases

Members		Statistics				
Case	Distance	Variable	Minimum	Mean	Maximum	St.Dev.
MA, Harwich	0.51	FAC1FSH9	–1.25	–0.64	0.62	0.61
MA, Rockport	0.34	FAC2FSH9	3.03	4.08	5.46	0.85
MA, Plymouth	0.52	FAC3FSH9	–0.90	–0.14	0.82	0.57
MA, Scituate	0.88	FAC4FSH9	–0.47	0.96	1.85	0.74
ME, Kittery	0.43	SOCFA1	–0.90	–0.28	0.38	0.40
NH, Hampton	0.47	SOCFA2	–0.30	0.07	0.31	0.22
NH, Portsmouth	0.29	SOCFA3	–0.92	–0.47	–0.20	0.24
RI, Narragansett	0.58					

continued

Appendix I.—(Continued).

Cluster 10 of 40 contains 1 case

Members		Statistics				
Case	Distance	Variable	Minimum	Mean	Maximum	St.Dev.
NY, New York	0.00	FAC1FSH9	0.61	0.61	0.61	–
		FAC2FSH9	4.31	4.31	4.31	–
		FAC3FSH9	–0.83	–0.83	–0.83	–
		FAC4FSH9	–4.77	–4.77	–4.77	–
		SOCFA1	–4.16	–4.16	–4.16	–
		SOCFA2	–4.73	–4.73	–4.73	–
		SOCFA3	15.44	15.44	15.44	–

Cluster 11 of 40 contains 32 cases

Members		Statistics				
Case	Distance	Variable	Minimum	Mean	Maximum	St.Dev.
DE, Frederica	0.29	FAC1FSH9	–0.13	0.01	0.26	0.11
DE, Milford	0.61	FAC2FSH9	–0.28	–0.04	0.81	0.27
DE, Millsboro	0.31	FAC3FSH9	–0.37	–0.05	0.50	0.18
MA, Onset	0.34	FAC4FSH9	–1.14	0.06	1.11	0.46
MD, Cambridge	0.24	SOCFA1	0.76	1.57	3.78	0.68
MD, Crisfield	0.54	SOCFA2	–1.82	–0.10	0.74	0.63
MD, Willards	0.38	SOCFA3	–1.08	0.18	1.05	0.49
MD, Berlin	0.42					
MD, Snow Hill	0.13					
ME, Eastport	0.58					
NC, Aurora	0.38					
NC, Belhaven	0.61					
NC, Gloucester	0.44					
NC, Marshallberg	0.56					
NC, Morehead City	0.26					
NC, Newport	0.32					
NC, Swan Quarter	0.75					
NC, Wilmington Beach	0.36					
NC, Bayboro	0.48					
NC, Vandemere	0.45					
NJ, Millville	0.32					
NJ, Keansburg	0.27					
NJ, Neptune City	0.44					
NY, Mastic Beach	0.42					
RI, East Providence	0.31					
RI, Woonsocket	0.34					
VA, Melfa	0.42					
VA, Onancock	0.45					
VA, Hallwood	0.61					
VA, Exmore	0.20					
VA, Nassawadox	0.85					
VA, Portsmouth	0.25					

continued

Appendix I.—(Continued).

Cluster 12 of 40 contains 38 cases

Members			Statistics			
Case	Distance	Variable	Minimum	Mean	Maximum	St.Dev.
DE, Lewes	0.34	FAC1FSH9	–0.61	–0.24	0.55	0.24
MA, Brewster	0.34	FAC2FSH9	–0.29	0.66	1.58	0.50
MA, Dennis	0.39	FAC3FSH9	–1.16	–0.29	0.39	0.33
MA, Eastham	0.31	FAC4FSH9	0.20	0.97	2.31	0.49
MA, South Dennis	0.23	SOCFA1	–1.17	–0.21	0.64	0.44
MA, Yarmouth	0.42	SOCFA2	–0.93	–0.09	0.82	0.41
MA, Vineyard Haven	0.32	SOCFA3	–1.13	–0.53	0.04	0.33
MA, Essex	0.25					
MA, Newburyport	0.71					
MA, Salisbury	0.40					
MA, Swampscott	0.38					
MA, Nantucket	0.38					
MA, Kingston	0.24					
MA, Middleboro	0.26					
MA, Ocean Bluff	0.33					
ME, Falmouth	0.37					
ME, Scarborough	0.47					
ME, South Portland	0.37					
ME, Hancock	0.43					
ME, Buxton	0.34					
ME, Kittery	0.34					
ME, Ogunquit	0.46					
ME, Saco	0.32					
ME, Wells	0.34					
NH, Newington	0.62					
NH, Dover	0.22					
NJ, Middletown	0.53					
NJ, Beach Haven	0.35					
NJ, Forked River	0.24					
NJ, Manahawkin	0.51					
NJ, Point Pleasant	0.31					
NJ, Toms River	0.26					
NJ, Tuckerton	0.41					
NJ, Waretown	0.37					
NY, Oceanside	0.64					
RI, Charlestown	0.43					
VA, Wachapreague	0.40					
VA, Poquoson	0.35					

Cluster 14 of 40 contains 9 cases

Members			Statistics			
Case	Distance	Variable	Minimum	Mean	Maximum	St.Dev.
MA, Gosnold	0.70	FAC1FSH9	–0.16	–0.07	–0.01	0.05
MD, Smith Island	0.49	FAC2FSH9	–0.26	–0.09	0.20	0.14
ME, Cranberry Isles	0.43	FAC3FSH9	–0.27	–0.09	–0.00	0.08
ME, Matinicus	0.43	FAC4FSH9	–0.14	0.15	0.68	0.25
ME, North Haven	0.51	SOCFA1	–1.05	0.09	1.89	0.96
ME, Roque Bluffs	0.64	SOCFA2	–6.51	–5.05	–3.37	1.06
NC, Smyrna	0.43	SOCFA3	–0.04	0.62	1.84	0.63
VA, Saxis	0.82					
VA, Tangier	0.51					

Cluster 15 of 40 contains 1 case

Members			Statistics			
Case	Distance	Variable	Minimum	Mean	Maximum	St.Dev.
MA, Gloucester	0.00	FAC1FSH9	1.53	1.53	1.53	–
		FAC2FSH9	25.40	25.40	25.40	–
		FAC3FSH9	–2.45	–2.45	–2.45	–
		FAC4FSH9	1.57	1.57	1.57	–
		SOCFA1	–0.03	–0.03	–0.03	–
		SOCFA2	–0.01	–0.01	–0.01	–
		SOCFA3	–0.30	–0.30	–0.30	–

continued

Appendix I.—(Continued).

Cluster 16 of 40 contains 1 case

Members		Statistics				
Case	Distance	Variable	Minimum	Mean	Maximum	St.Dev.
NJ, Cape May	0.00	FAC1FSH9	8.09	8.09	8.09	–
		FAC2FSH9	1.28	1.28	1.28	–
		FAC3FSH9	6.75	6.75	6.75	–
		FAC4FSH9	3.01	3.01	3.01	–
		SOCFA1	0.40	0.40	0.40	–
		SOCFA2	0.07	0.07	0.07	–
		SOCFA3	–0.44	–0.44	–0.44	–

Cluster 17 of 40 contains 1 case

Members		Statistics				
Case	Distance	Variable	Minimum	Mean	Maximum	St.Dev.
MA, Chatham	0.00	FAC1FSH9	–2.58	–2.58	–2.58	–
		FAC2FSH9	12.65	12.65	12.65	–
		FAC3FSH9	1.28	1.28	1.28	–
		FAC4FSH9	0.82	0.82	0.82	–
		SOCFA1	–0.17	–0.17	–0.17	–
		SOCFA2	–0.73	–0.73	–0.73	–
		SOCFA3	–0.37	–0.37	–0.37	–

Cluster 18 of 40 contains 1 case

Members		Statistics				
Case	Distance	Variable	Minimum	Mean	Maximum	St.Dev.
ME, Portland	0.00	FAC1FSH9	5.16	5.16	5.16	–
		FAC2FSH9	11.07	11.07	11.07	–
		FAC3FSH9	–0.70	–0.70	–0.70	–
		FAC4FSH9	–14.62	–14.62	–14.62	–
		SOCFA1	0.09	0.09	0.09	–
		SOCFA2	0.27	0.27	0.27	–
		SOCFA3	–0.12	–0.12	–0.12	–

Cluster 19 of 40 contains 22 cases

Members		Statistics				
Case	Distance	Variable	Minimum	Mean	Maximum	St.Dev.
CT, Bridgeport	0.66	FAC1FSH9	–0.15	0.01	0.36	0.11
CT, Norwalk	0.40	FAC2FSH9	–0.27	–0.02	0.48	0.20
CT, Stamford	0.45	FAC3FSH9	–0.23	–0.02	0.30	0.15
CT, New Haven	0.62	FAC4FSH9	–1.18	–0.31	0.33	0.44
DE, Wilmington	0.60	SOCFA1	–0.48	0.67	2.13	0.80
MA, Lynn	0.34	SOCFA2	0.04	0.52	1.19	0.26
MA, Framingham	0.49	SOCFA3	0.73	1.72	3.67	0.81
MA, Randolph	0.47					
MA, Revere	0.49					
MA, Worcester	0.17					
NJ, Ventnor City	0.30					
NJ, Jersey City	0.77					
NJ, Long Branch	0.24					
NJ, Clifton	0.23					
NY, Baldwin	0.44					
NY, Glen Cove	0.27					
NY, Inwood	0.36					
NY, Staten Island	0.39					
NY, Bay Shore	0.26					
PA, Philadelphia	0.60					
RI, Providence	0.73					
VA, Richmond	0.47					

Cluster 20 of 40 contains 1 case

Members		Statistics				
Case	Distance	Variable	Minimum	Mean	Maximum	St.Dev.
ME, Harpswell	0.00	FAC1FSH9	–1.75	–1.75	–1.75	–
		FAC2FSH9	5.45	5.45	5.45	–
		FAC3FSH9	–2.57	–2.57	–2.57	–
		FAC4FSH9	9.44	9.44	9.44	–
		SOCFA1	–0.57	–0.57	–0.57	–
		SOCFA2	–1.58	–1.58	–1.58	–
		SOCFA3	–0.21	–0.21	–0.21	–

continued

Appendix I.—(Continued).

Cluster 23 of 40 contains 22 cases

Members

Case	Distance
DE, Bowers	0.15
MA, Chilmark	0.58
ME, Brookline	0.17
ME, Brooksville	0.18
ME, Castine	0.35
ME, Franklin	0.39
ME, Sorrento	0.37
ME, Sullivan	0.28
ME, Tremont	0.44
ME, Isle au Haut	0.24
ME, St. George	0.34
ME, Bremen	0.49
ME, Bristol	0.42
ME, Southport	0.33
ME, Georgetown	0.45
ME, Columbia	0.36
ME, Jonesboro	0.17
NC, Harkers Island	0.52
NC, Ocracoke	0.22
NC, Sneads Ferry	0.49
NY, Orient	0.42
VA, Onley	0.36

Statistics

Variable	Minimum	Mean	Maximum	St.Dev.
FAC1FSH9	−0.33	−0.10	0.04	0.11
FAC2FSH9	−0.28	0.13	1.38	0.48
FAC3FSH9	−0.43	−0.09	0.09	0.11
FAC4FSH9	−0.36	0.06	1.07	0.37
SOCFA1	−0.79	−0.05	0.87	0.46
SOCFA2	−2.75	−1.70	−0.87	0.56
SOCFA3	−1.07	−0.53	0.11	0.30

Cluster 25 of 40 contains 35 cases

Members

Case	Distance
CT, Branford	0.26
CT, East Lyme	0.29
CT, Groton	0.45
CT, Mystic	0.25
CT, Noank	0.27
MA, Danvers	0.34
MA, Ipswich	0.27
MA, Methuen	0.42
MA, Nahant	0.31
MA, Salem	0.44
MA, Saugus	0.16
MA, Quincy	0.36
MA, Weymouth	0.21
MA, Duxbury	0.59
MA, Hingham	0.46
MA, Hull	0.40
MA, Pembroke	0.17
ME, Cape Elizabeth	0.35
ME, Bath	0.34
ME, Eliot	0.28
ME, Kennebunk	0.25
ME, York	0.41
ME, York Harbor	0.20
NJ, Atlantic City	0.36
NJ, Belmar	0.26
NJ, Brielle	0.25
NY, Island Park	0.49
NY, Point Lookout	0.46
NY, East Hampton	0.46
NY, East Quogue	0.33
NY, West Islip	0.28
RI, Warwick	0.24
RI, Jamestown	0.26
RI, Cranston	0.40
RI, Westerly	0.35

Statistics

Variable	Minimum	Mean	Maximum	St.Dev.
FAC1FSH9	−0.47	−0.13	0.14	0.14
FAC2FSH9	−0.15	0.55	1.45	0.35
FAC3FSH9	−0.47	0.07	0.66	0.29
FAC4FSH9	−1.58	−0.56	0.18	0.43
SOCFA1	−1.75	−0.47	0.33	0.49
SOCFA2	−0.28	0.28	0.82	0.27
SOCFA3	−0.67	−0.18	0.70	0.38

continued

Appendix I.—(Continued).

Cluster 28 of 40 contains 1 case

Members		Statistics				
Case	Distance	Variable	Minimum	Mean	Maximum	St.Dev.
MA, Boston	0.00	FAC1FSH9	1.84	1.84	1.84	—
		FAC2FSH9	5.47	5.47	5.47	—
		FAC3FSH9	0.25	0.25	0.25	—
		FAC4FSH9	−7.88	−7.88	−7.88	—
		SOCFA1	0.32	0.32	0.32	—
		SOCFA2	0.35	0.35	0.35	—
		SOCFA3	2.75	2.75	2.75	—

Cluster 31 of 40 contains 1 case

Members		Statistics				
Case	Distance	Variable	Minimum	Mean	Maximum	St.Dev.
VA, Newport	0.00	FAC1FSH9	5.30	5.30	5.30	—
		FAC2FSH9	−2.58	−2.58	−2.58	—
		FAC3FSH9	1.52	1.52	1.52	—
		FAC4FSH9	5.13	5.13	5.13	—
		SOCFA1	0.61	0.61	0.61	—
		SOCFA2	0.34	0.34	0.34	—
		SOCFA3	0.83	0.83	0.83	—

Cluster 32 of 40 contains 6 cases

Members		Statistics				
Case	Distance	Variable	Minimum	Mean	Maximum	St.Dev.
MA, Orleans	0.52	FAC1FSH9	−1.09	−0.55	−0.18	0.32
MA, Truro	0.65	FAC2FSH9	1.59	2.35	3.01	0.55
MA, Wellfleet	0.53	FAC3FSH9	−0.70	−0.21	0.29	0.41
ME, Bar Harbor	0.32	FAC4FSH9	−0.71	0.24	1.27	0.71
ME, Southwest Harbor	0.42	SOCFA1	−0.24	0.66	1.49	0.62
ME, Boothbay Harbor	0.44	SOCFA2	−1.02	−0.29	0.48	0.65
		SOCFA3	−1.64	−1.11	−0.68	0.38

Cluster 35 of 40 contains 8 cases

Members		Statistics				
Case	Distance	Variable	Minimum	Mean	Maximum	St.Dev.
DE, Leipsic	0.26	FAC1FSH9	−0.11	−0.04	0.00	0.04
MA, Buzzards Bay	0.33	FAC2FSH9	−0.27	−0.09	0.16	0.15
ME, Gorham	0.29	FAC3FSH9	−0.22	−0.07	0.17	0.11
ME, Machias	0.43	FAC4FSH9	−0.77	−0.11	0.16	0.30
NC, Elizabeth City	0.56	SOCFA1	1.27	2.00	2.96	0.52
NH, Durham	0.12	SOCFA2	0.18	1.21	2.84	0.76
NJ, Wildwood	0.21	SOCFA3	−1.48	−1.13	−0.01	0.50
RI, Kingston	0.64					

Cluster 36 of 40 contains 6 cases

Members		Statistics				
Case	Distance	Variable	Minimum	Mean	Maximum	St.Dev.
CT, Stonington	0.68	FAC1FSH9	−0.38	−0.01	0.87	0.51
MA, Falmouth	0.40	FAC2FSH9	0.26	0.65	1.16	0.35
NJ, Sea Isle City	0.50	FAC3FSH9	0.83	1.48	2.46	0.72
NY, Mattituck	0.35	FAC4FSH9	−1.41	−0.25	0.74	0.79
RI, Little Compton	0.63	SOCFA1	−0.69	0.11	0.72	0.57
RI, Tiverton	0.40	SOCFA2	−0.71	0.06	0.81	0.52
		SOCFA3	−1.06	−0.77	−0.56	0.22

continued

Appendix I.—(Continued).

Cluster 38 of 40 contains 4 cases

Members		Statistics				
Case	Distance	Variable	Minimum	Mean	Maximum	St.Dev.
MA, Sandwich	0.48	FAC1FSH9	–0.63	–0.29	0.33	0.42
NC, Beaufort	0.81	FAC2FSH9	0.56	1.84	2.94	1.00
VA, Chincote	0.50	FAC3FSH9	0.85	1.62	2.35	0.61
VA, Virginia	0.72	FAC4FSH9	0.68	1.20	2.41	0.82
		SOCFA1	–0.51	0.33	1.04	0.81
		SOCFA2	–1.20	–0.28	0.14	0.62
		SOCFA3	–0.66	–0.05	1.11	0.79

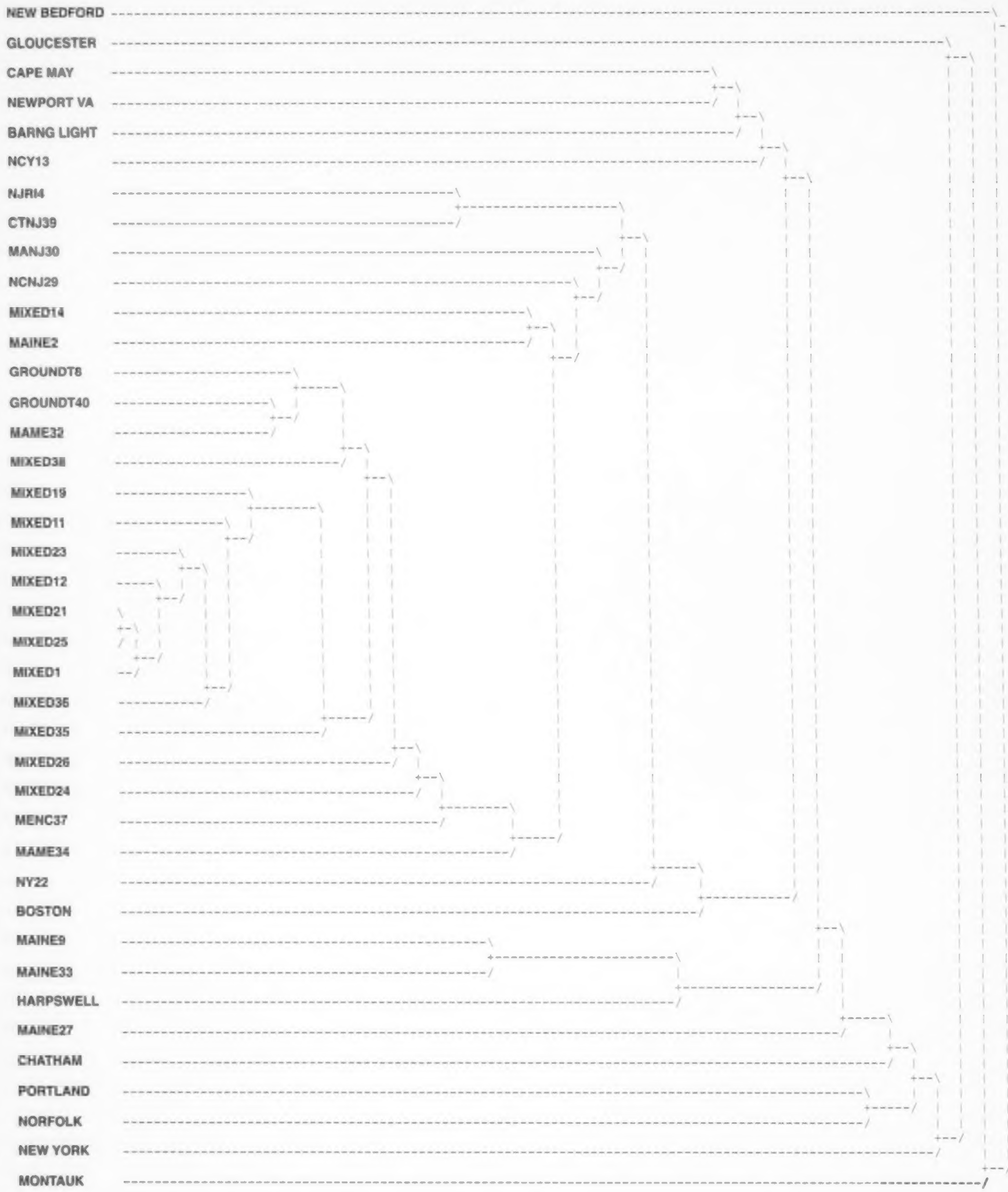
Cluster 40 of 40 contains 9 cases

Members		Statistics				
Case	Distance	Variable	Minimum	Mean	Maximum	St.Dev.
MA, Barnstable	0.29	FAC1FSH9	–0.84	–0.56	–0.40	0.14
MA, Westport	0.45	FAC2FSH9	2.05	2.78	3.44	0.48
MA, Beverly	0.32	FAC3FSH9	–0.01	0.34	0.96	0.37
MA, Marblehead	0.52	FAC4FSH9	–1.52	–0.71	0.17	0.62
MA, Newburyport	0.35	SOCFA1	–1.40	–0.34	0.24	0.49
MA, Marshfield	0.37	SOCFA2	–0.26	0.32	0.76	0.37
ME, Kennebunkport	0.46	SOCFA3	–1.08	–0.46	–0.19	0.27
NH, Rye	0.35					
NH, Seabrook	0.36					

Appendix II.—Hierarchial Cluster Analysis of K-means 40 Clusters. Distance metric is Euclidean distance. Median linkage method. Single port clusters use port name rather than cluster number.

Cluster containing	and	Cluster containing	Were joined at distance	No. of members in new cluster
MIXED25		MIXED21	0.411	2
MIXED1		MIXED25	0.378	3
MIXED1		MIXED12	0.437	4
MIXED1		MIXED23	0.599	5
MIXED36		MIXED1	0.624	6
MIXED36		MIXED11	0.631	7
MIXED36		MIXED19	0.639	8
GROUNDT40		MAME32	0.674	2
GROUNDT8		GROUNDT40	0.665	3
MIXED35		MIXED36	0.773	9
GROUNDT8		MIXED38	0.797	4
GROUNDT8		MIXED35	0.779	13
GROUNDT8		MIXED26	0.850	14
GROUNDT8		MIXED24	0.773	15
GROUNDT8		MENC37	0.945	16
CTNJ39		NJRI4	1.023	2
MAINE33		MAINE9	1.196	2
GROUNDT8		MAME34	1.256	17
MIXED14		MAINE2	1.353	2
MIXED14		GROUNDT8	1.294	19
MIXED14		NCNJ29	1.482	20
MIXED14		MANJ30	1.516	21
MIXED14		CTNJ39	1.772	23
NY22		MIXED14	1.593	24
HARPSWELL		MAINE33	2.329	3
NY22		BOSTON	2.351	25
NEWPORT VA		CAPE MAY	2.835	2
BARNG LIGHT		NEWPORT VA	2.578	3
NCNY13		BARNG LIGHT	2.541	4
NCNY13		NY22	2.918	29
NCNY13		HARPSWELL	2.660	32
NCNY13		MAINE27	2.725	33
PORTLAND		NORFOLK	3.657	2
NCNY13		CHATHAM	3.703	34
NCNY13		PORTLAND	4.775	36
NEW YORK		NCNY13	4.930	37
NEW YORK		GLOUCESTER	7.041	38
NEW YORK		MONTAUK	11.146	39
NEW BEDFORD		NEW YORK	13.814	40

Appendix II.—(Continued).



Appendix III.—K-means clustering of K-means 40 clusters. K-means splitting 40 cases into 10 groups (single port clusters use port name rather than cluster number).

Summary statistics for all cases

Variable	Between SS	df	Within SS	df	F-ratio
LARGE	1590.686	9	86.966	30	60.970
SMALL	784.370	9	88.921	30	29.403
MEDIUM	674.282	9	61.448	30	36.577
RISING	1039.884	9	178.613	30	19.407
POVERTY	28.208	9	19.093	30	4.925
URBAN	141.997	9	40.185	30	11.779
ETHNIC	232.583	9	36.724	30	21.111
TOTAL	4492.010	63	511.949	210	

Cluster 1 of 10 contains 21 cases

Members		Statistics				
Case	Distance	Variable	Minimum	Mean	Maximum	St.Dev.
MIXED1	0.80	LARGE	–0.64	0.13	3.30	0.88
MAINE2	1.34	SMALL	–1.33	1.09	4.13	1.42
GROUNDT8	1.30	MEDIUM	–0.99	0.20	2.11	0.78
MIXED11	0.62	RISING	–2.92	–0.19	3.78	1.56
MIXED12	0.62	POVERTY	–1.17	0.44	2.06	0.84
MIXED19	0.81	URBAN	–2.74	–0.19	1.21	0.96
MIXED21	0.52	ETHNIC	–1.13	0.06	4.37	1.22
NY22	2.03					
MIXED23	0.75					
MIXED24	1.14					
MIXED25	0.48					
MIXED26	0.91					
NCNJ29	1.58					
MANJ30	1.77					
MAME32	0.74					
MAME34	1.66					
MIXED35	1.02					
MIXED36	0.62					
MENC37	0.99					
MIXED38	0.82					
GROUNDT40	0.83					

Cluster 2 of 10 contains 3 cases

Members		Statistics				
Case	Distance	Variable	Minimum	Mean	Maximum	St.Dev.
NORFOLK	2.02	LARGE	1.84	3.29	5.16	1.70
PORTLAND	2.18	SMALL	2.89	6.48	11.07	4.18
BOSTON	2.06	MEDIUM	–0.70	1.02	3.51	2.21
		RISING	–15.71	–12.74	–7.88	4.24
		POVERTY	0.09	0.51	1.12	0.54
		URBAN	0.27	0.34	0.41	0.07
		ETHNIC	–0.12	1.24	2.75	1.44

Cluster 3 of 10 contains 1 case

Members		Statistics				
Case	Distance	Variable	Minimum	Mean	Maximum	St.Dev.
NEW BEDFORD	0.00	LARGE	39.65	39.65	39.65	–
		SMALL	1.12	1.12	1.12	–
		MEDIUM	–0.68	–0.68	–0.68	–
		RISING	6.91	6.91	6.91	–
		POVERTY	1.94	1.94	1.94	–
		URBAN	0.10	0.10	0.10	–
		ETHNIC	1.50	1.50	1.50	–

continued

Appendix III.—(Continued).

Cluster 4 of 10 contains 6 cases

Members		Statistics				
Case	Distance	Variable	Minimum	Mean	Maximum	St.Dev.
NJRI4	1.97	LARGE	–1.16	2.31	8.09	3.61
BARNG LIGHT	2.29	SMALL	–2.58	0.42	1.67	1.54
NCNY13	2.11	MEDIUM	1.52	5.88	10.15	2.80
CAPE MAY	2.25	RISING	–2.18	2.69	8.33	3.76
NEWPORT VA	2.51	POVERTY	–0.58	0.07	0.61	0.41
CTNJ39	1.61	URBAN	–1.31	–0.21	0.34	0.74
		ETHNIC	–0.74	0.08	0.91	0.67

Cluster 5 of 10 contains 1 case

Members		Statistics				
Case	Distance	Variable	Minimum	Mean	Maximum	St.Dev.
CHATHAM	0.00	LARGE	–2.58	–2.58	–2.58	–
		SMALL	12.65	12.65	12.65	–
		MEDIUM	1.28	1.28	1.28	–
		RISING	0.82	0.82	0.82	–
		POVERTY	–0.17	–0.17	–0.17	–
		URBAN	–0.73	–0.73	–0.73	–
		ETHNIC	–0.37	–0.37	–0.37	–

Cluster 6 of 10 contains 1 case

Members		Statistics				
Case	Distance	Variable	Minimum	Mean	Maximum	St.Dev.
MONTAUK	0.00	LARGE	–4.46	–4.46	–4.46	–
		SMALL	2.60	2.60	2.60	–
		MEDIUM	22.73	22.73	22.73	–
		RISING	18.56	18.56	18.56	–
		POVERTY	0.91	0.91	0.91	–
		URBAN	–0.94	–0.94	–0.94	–
		ETHNIC	0.37	0.37	0.37	–

Cluster 7 of 10 contains 1 case

Members		Statistics				
Case	Distance	Variable	Minimum	Mean	Maximum	St.Dev.
NEW YORK	0.00	LARGE	0.61	0.61	0.61	–
		SMALL	4.31	4.31	4.31	–
		MEDIUM	–0.83	–0.83	–0.83	–
		RISING	–4.77	–4.77	–4.77	–
		POVERTY	–4.16	–4.16	–4.16	–
		URBAN	–4.73	–4.73	–4.73	–
		ETHNIC	15.44	15.44	15.44	–

Cluster 8 of 10 contains 3 cases

Members		Statistics				
Case	Distance	Variable	Minimum	Mean	Maximum	St.Dev.
MAINE9	1.11	LARGE	–1.75	–1.36	–0.77	0.52
HARPSWELL	1.71	SMALL	4.50	5.41	6.29	0.90
MAINE33	0.97	MEDIUM	–2.57	–2.26	–1.73	0.46
		RISING	2.98	5.64	9.44	3.38
		POVERTY	–0.57	–0.17	0.33	0.46
		URBAN	–5.89	–3.91	–1.58	2.18
		ETHNIC	–0.21	0.19	0.64	0.43

continued

Appendix III.—(Continued).

Cluster 9 of 10 contains 2 cases

Members		Statistics				
Case	Distance	Variable	Minimum	Mean	Maximum	St.Dev.
MIXED14	0.97	LARGE	−0.07	−0.05	−0.03	0.03
MAINE27	0.97	SMALL	−0.09	0.02	0.14	0.16
		MEDIUM	−0.09	−0.04	0.02	0.08
		RISING	−0.37	−0.11	0.15	0.37
		POVERTY	−2.35	−1.13	0.09	1.73
		URBAN	−9.43	−7.24	−5.05	3.10
		ETHNIC	0.62	1.04	1.45	0.59

Cluster 10 of 10 contains 1 case

Members		Statistics				
Case	Distance	Variable	Minimum	Mean	Maximum	St.Dev.
GLOUCESTER	0.00	LARGE	1.53	1.53	1.53	–
		SMALL	25.40	25.40	25.40	–
		MEDIUM	−2.45	−2.45	−2.45	–
		RISING	1.57	1.57	1.57	–
		POVERTY	−0.03	−0.03	−0.03	–
		URBAN	−0.01	−0.01	−0.01	–
		ETHNIC	−0.30	−0.30	−0.30	–

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